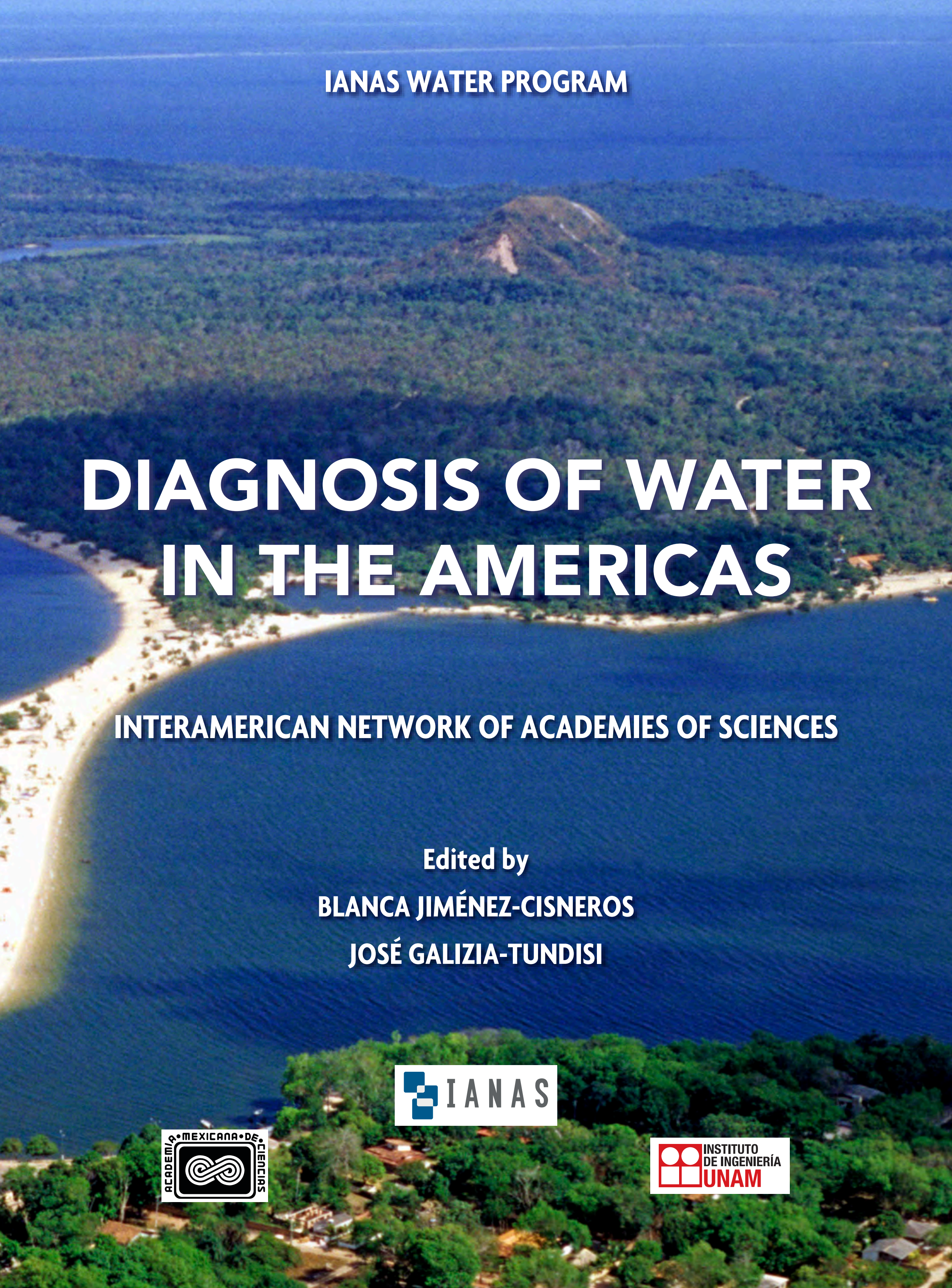

IANAS WATER PROGRAM

DIAGNOSIS OF WATER IN THE AMERICAS

INTERAMERICAN NETWORK OF ACADEMIES OF SCIENCES

Edited by

BLANCA JIMÉNEZ-CISNEROS

JOSÉ GALIZIA-TUNDISI

IANAS

ACADEMIA MEXICANA DE CIENCIAS

INSTITUTO DE INGENIERÍA UNAM

DIAGNOSIS OF WATER IN THE AMERICAS
IANAS WATER PROGRAM

Academia Mexicana de Ciencias
Calle Cipreses s/n, km 23.5 de la
Carretera Federal México - Cuernavaca,
San Andrés Totoltepec,
Tlalpan, C.P. 14400, México, D.F.
www.amc.mx
academia@amc.edu.mx
Tel. (52 55) 58 49 49 05

Editorial Coordination:
Mexican Academy of Sciences
Regina M. Alarcón-Contreras
María Luisa Torregrosa y Armentia

Editors:
Blanca Jiménez-Cisneros (Mexican Academy of Sciences)
José Galizia-Tundisi (Brazilian Academy of Sciences)

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Design:
Imelda Paredes (Mexican Academy of Sciences)
Ixchel Obregón

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Prologue

This book provides, for the first time, an assessment of water resources in the Americas. We report the diagnosis of 15 countries.

Water is vital for human life, we use water to drink, to grow our food, to clean up our environment, we use it as a way of transport, for power generation, and a for thousands of other purposes. Water resources are limited and are also unevenly distributed in the regions of the world.

In America, the Atacama region in Chile is famous for an almost total absence of rain, in the same sense, the communities of the arid deserts in southwestern North America, are engaged in a constant battle against lack of water for human life. In contrast, other regions such as the Amazon basin are equally famous for its abundance of water, however; even that abundance can be threatened by changing weather patterns.

There is one fact about water that stands above among any other: the current patterns of water used are unsustainable in many regions of the world, including major portions of the American continent.
One of the greatest challenges of the XXI century will be to improve our management and use of water, to ensure that this critical resource supports a world population of nine billion or more in 2050. A substantial contribution to overcome this challenge is the effective use of science to improve the use of our water resources

The effective use of science means not only to create new knowledge, but also to translate this scientific knowledge towards the open public, so that new technologies and new concepts can be implemented quickly.

This volume is the result of a project of the "Water Network" which is part of the "Inter-American Network of Academies of Science" (IANAS). Our organization is the network of science academies on the American Continent, created from the initiative and the spirit encouraged by the operation of the "Inter-Academic Panel" (IAP), which brings together more than one hundred national science academies worldwide.

IANAS members are all the countries that have established an academy of sciences. IANAS's mission is to foster cooperation between the academies of sciences and promote their participation as relevant actors in the development of the countries of the region. IANAS bases its operation on programs. The Water Program completes its first stage with the publication of this volume: Diagnosis of water in the Americas. The diagnosis of each country is the result of the work of scientific networks in each of the member academies of IANAS. This work was coordinated by José Galizia Tundisi from Brazil, and Blanca Jiménez from Mexico. Both of them co-chair the program.

IANAS can quickly establish connections between scientists who have the best current scientific information and those instances in each country that requires it for decision making. One of the goals of IANAS is to provide fundamental information to the involved authorities to undertake actions to properly allocate water resources. We also identified opportunities in the design of new processes that improve water use in order to achieve sustainability in the long term. Finally, we recommend contacting the national academies of sciences in the Americas as partners to provide expert advice to decision-makers, locally and nationally.
We thank all of our American Continent scientists who participated carrying out this volume; as well as to the global network of science academies (IAP) for providing their financial support. Also to the Mexican Academy of Sciences and the Institute of Engineering of the National Autonomous University of Mexico for editing, printing and distributing this book.

Congratulations on this cherished effort

Michael Clegg and Juan Pedro Laclette
Co-Chairs of IANAS
June 2013

Preface

Availability of good quality water in extended amounts is a key element to economically and socially develop continents, countries and regions.

The American continent hosts a diverse group of countries which have geographical, historical, economic, social and ecological differences, generating different structures of water resource's availability and management.

In these countries and regions, water can be abundant, scarce or even rare. The multiple uses of water in agriculture, industry or domestic supply, is a complex matter that requires implementing an integrated handling which is difficult to accomplish. Also, since human activities have a daily impact on surface and underground water and given the high rate of worldwide urbanization; the availability of the resource is deteriorated on daily bases by pollution and fatigue causing a severe negative effect to the public health and to the ecosystems; thus creating a serious safety problem for the entire world.

We hope that the inputs presented in this book, be representative of the diversity in the availability of water, pollution problems and public policy strategies on the continent. The policy of water management change considerably in the countries: laws and public policies are diverse and are found at different stages of development. The comparative description of the status of water policy and its availability or lack of it in such different countries will certainly be useful information to increase the exchange of policies and technical experiences.

The editors are confident that this book will be very useful to strengthen the study of water resources in the different countries of the American continent, providing in this context its share to the development of public policies.

The editors thank extensively the efforts of all the authors of this text as well as those who participated as coordinators of national texts as members of the IANAS Water Network. Blanca Jiménez-Cisneros PhD and José Galizia-Tundisi PhD, thank the Mexican Academy of Sciences, the Brazilian Academy of Sciences and the IANAS Directive Committee for their support in the production of this text. The editors also acknowledge the support of the Engineering Institute of the National Autonomous University of Mexico.

Blanca Jiménez-Cisneros
Co-Chair Water Program
IANAS

José Galizia-Tundisi
Co-Chair Water Program
IANAS
June 2013

Presentation

In 2002, the Mexican Academy of Sciences (MAS) established specialized committees to undertake studies on various key issues and make recommendations to guide decision-making at various levels of government. In particular, it created the Water Committee, a working group designed to use scientific knowledge to achieve the sustainable, integral use of water, thereby enhancing citizens' well-being. Mexico, like many other countries, faces several water-related problems including shortages, pollution, the need for improved administration coupled with the lack of ecological management and the impact of climate change on the hydrological cycle.

In November 2007, the Inter-American Network of Academies of Sciences (IANAS), created the Water Program, since access to clean water is one of the main problems facing mankind. The problem has been exacerbated by a long history of excessive, inappropriate water use, pollution and increased demand.

Poor water resource management is one of the main causes of the loss of opportunities for the sustainable development of several countries and the Academies of Science comprising IANAS consider that this complex situation requires scientific and technological action and effective management that will contribute to better use of existing supplies, permit the recovery and conservation of degraded areas and groundwater reserves and develop public policies to ensure the necessary water resources for future generations. Together, the Academies constitute an excellent forum for the dissemination of quality information and serve as an expert interlocutor for supporting decision-makers at the national and regional level.

Within this framework, the "Diagnosis of Water in the Americas" was developed, in which each Academy provided a strategic overview of the water resources of its respective country. The documents were prepared by multidisciplinary experts and make a valuable contribution to the debate on water policies in the Americas. We obviously have top-level scientists and technologists who provide solutions to the problems of the region and I am confident that this joint assessment will be vital to addressing the challenge of water for the future of the planet.

The book condenses the opinions and knowledge of 68 experts from 15 countries, coordinated by Dr. Blanca Jiménez-Cisneros of the Water Committee of the Mexican Academy of Sciences and Dr. José Galizia-Tundisi of the Brazilian Academy of Sciences, who jointly coordinate the IANAS Water Program. Thanks and congratulations are due to all the authors.

José Franco
President
Mexican Academy of Sciences
June 2013

Foreword

Glacier Perito Moreno

Considerations on the Situation of Water Resources in Argentina

"And time, irreversible, that hurts us and flees,
water, is nothing more than one of your metaphors".
J. L. Borges ("Poem for the Fourth Element", 1964).

José María Dagnino Pastore[1], Adolfo Sturzenegger[1], Eduardo H. Charreau[2], Oscar Vardé[3], Conrado Bauer[3] y Pablo Bereciartúa[1]

[1]Academia Nacional de Ciencias Económicas

[2]Academia Nacional de Ciencias Exactas, Fisicas y Naturales

[3]Academia Nacional de Ingeniería

1. Introduction

The National Academies sponsoring the present work have summoned a group of university professionals concerned with the problems regarding water in Argentina. They have been dedicated to analyzing the situation, gathering part of the generally disperse and discontinuous information available until 2008/2010, and have put forward their opinions in this outreach project. Our intention is to point out the importance of the issues regarding water in our country and the need to adopt the most urgent measures required by the current situation. At the same time, we intend to promote the short term expansion of work programs that facilitate analysis and drive comprehensive organization and effective functioning of systems for data collection and the subsequent gathering and spreading of much needed on-going and systematic information. The purpose of these activities is to cooperate with public and private decision-makers to diagnose and evaluate alternatives that promote agreements on priority workable proposals. In this way, it will be possible to back the prompt and adezquate assignment of budget resources and legitimate complementary income to develop policies and projects that harmoniously sustain the achievement of two basic objectives: to satisfy the social function of water (equity) and allow its productive use (growth) and thus contribute to the sustainable and comprehensive development of the country.

The international acknowledgement of water as the essential support for life and its future is unanimous. This entails the pressing need to care for its management, quality and rational use, and consequently to protect its natural cycle and the ecosystems of surface and groundwater basins, as well as expand and consolidate the services that purify and provide safe water, collect, treat and dispose of wastewaters and prevent flooding and droughts. The activities mentioned are fundamental world-wide elements for promoting health and the social integration and development of all nations. The "United Nations Conference for Sustainable Development" held in Johannesburg in 2002, placed water first when identifying the five issues to receive priority attention.

Each country, including Argentina, must commit especially to plan and bring about actions that lead to enabling appropriate water availability and its more sensible, rational and fair use, ensuring the continuity and preservation of a supply that satisfies not only human needs regarding quantity, quality, time and place, but also productive activities, ecosystem conservation and biodiversity.

The adoption and fulfillment of these objectives are a responsibility shared by governments, businessmen, specialized professionals, technicians and workers, as well as the general population; their knowledge regarding the importance of water and the urgent need to preserve its proper use must constitute the necessary support that will allow to make reasonable proposals for policies and actions and put them into practice. With such broad participation, it will be possible to make general, regional and sectoral interests compatible, and to promote the appropriate legislation, management, execution and updating of structural measures (physical works) and non-structural measures (systems for training, setting rates, regulating, controlling and diffusion). These actions will encourage and enable effective water governance.

Since 2008, the authors have met periodically to promote and organize the content and design of this document. They have been through the information available, even when it has been incomplete, and have come up with and discussed proposals which have led to the publication of this study as an additional contribution for the outreaching and analysis of the problems created by the use of water. It is not only directed to specialists in the subject, but also to the press and for distribution to the general public.

In conclusion, the objective is directed to reveal relevant aspects of the issue in an orderly manner, as a summary, as a reminder of basic information and as a reference contribution to move forward on ideas and proposals that allow the establishment of priorities for action in order to face current and future challenges in our country. The following persons have coordinated the production of the report and proposals "The Issue of Water": the ex-president of the Academia Nacional de Ciencias Económicas (National Academy for Economic Sciences) José María Dagnino Pastore, PhD and its current president Adolfo Sturzenegger, PhD; in collaboration with the president of the Academia Nacional de Ciencias Exactas, Físicas y Naturales (National Academy for Exact, Physical and Natural Sciences) Eduardo H. Charreau, PhD; and the support for publication and diffusion of the report from Oscar Verde, president of the Academia Nacional de Ingeniería (National Academy for Engineering).

The list of professionals who have personally participated in the development of the report includes Conrado Bauer, Gustavo Devoto and Luis U. Jáuregui, hydraulic and civil engineers from the National Academy of Engineering; Pablo Bereciartúa, hydraulic and civil engineer; Emilio Lentini and Juan Antonio Zapata. PhD., specialists in economics; and Mario Valls PhD., expert in water law. We finally express our acknowledgement regarding the contributions on water management of Javier Pascuchi and the special contributions of the civil engineering Luciana Manzelli, Federica Brenner and Augusto Mercadier, economists, and Susana D.R. Savoia, PhD. (Technical Secretary of the National Academy for Economic Sciences).

2. Context

Water has become a critical resource for the development of societies in the XXIst century, to the extent that when the 2002 UN Conference for Sustainable Development in Johannesburg selected the five most important topics necessary for sustainable development, it placed water at the top of the list, as mentioned in the foreword. Previously in 1993, the United Nations had established the 22 of March as "WORLD WATER DAY" to represent the importance of the issue and its continuous renovation.

In a more general framework, the concern over water results from two tendencies: a) rapid growth of demand brought about by an increase in population, growing economic development and a more concentrated urban population, all of which stimulate the demand to satisfy its various uses, no matter if they regard basic vital needs, food production, hygiene, conservation of the environment, or development in its broadest sense; b) a simultaneous increase in the factors that limit the quantity and quality of the water supply: while the quantity available is determined by the characteristics of ecosystems and the hydrological cycle in each geographical area, quality decreases due to contamination and poor practices. These tendencies result in the obvious gaps that grow between the needs that must be satisfied and the hydric resources apt to meet them. Although these circumstances are present world-wide, they present specific conditions in each region and every country.

In recent years, and in response to the evidence of the challenges mentioned above, there has been a growing awareness regarding this matter, which can be called "the issue of water". Within the context of the paradigm of sustainable development, it is necessary to come up with strategies that are focused on reducing the gaps between a growing demand (that requires increasing rationality and control) and the capacity to satisfy it. Therefore it is necessary to consider the issue of water within the concept of integrated management of hydric resources.

2.1 Objectives

Based on the collection and analysis of the information available on a worldwide, regional and national scale, the following aspects have been developed in the present work:

- To identify the main topics related to the "issue of water", and its global and regional situation, particularly in Latin America (points 3 and 4), with brief references to our country.
- To present the specific characteristics of each one of these topics in Argentina, so as to offer elements that describe their current situation and recent evolution (point 5.1).
- To create of a series of conclusions that lay down current and future challenges, as well as certain actions that are considered a priority to meet them (points 5.2 and 5.3).

3. The Sustainability of the Use of Hydric Resources; General Situation and Outlook.

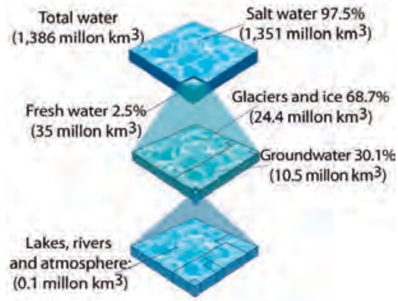
3.1 Evaluation of the Availability of Hydric Resources

3.1.1 Water in the World

The world contains a large amount of available water, although it is unevenly distributed in time and space. It is found naturally in several states: solid, liquid and gas, within different positions in the air, on the Earth's surface, underground and in the oceans, and has a variable content of salts (FIG. 1.) (Ramsar, 2009).

Worldwide, the annual average precipitation is 119,000 km^3 of which nearly 72,000 km^3 evaporate into the atmosphere. The remaining 47,000 km^3 flow into lakes, reservoirs and water currents or they filter into the land, partially feeding aquifers. It is calculated that between 9,000 km^3 and 14,000 km^3 of water can be used by man (Table 1).

Annual water extraction for human use reaches 3,600 km^3 while rivers require 2,350 km^3 to maintain minimum ecological flow, therefore, 5,950 km^3 of the easily available water resources are committed. This shows how fragile the situation is, considering demographic projections and water demand as well as accessibility and geographic location of the surplus (FAO, 2002). Hydric resources are under the pressure of a combination of natural and human factors. Climate change and the ordinary variation in geographical distribution of water are natural aspects that make sustainable development of hydric resources difficult. Likewise, water resources are influenced by the following main anthropic factors: population growth, especially in areas where water is scarce; major demographic changes regarding distribution and concentration of the population, as when people move from rural to urban areas; greater demand for food security and socioeconomic wellbeing; greater competition between users, and industrial, municipal and agricultural pollution.



SOURCE: SHIKLOMANOV AND RODDA (2003), WATER AND CROPS", ONU 2002.

FIG. 1. Global Distribution of Water in the World

Table 1. The Average Annual Precipitation in the World

Region	Precipitation		Evapotranspiration		Surplus	
	mm/year	km^3/year	mm/year	km^3/year	mm/year	km^3/year
Europe	700	8.290	507	5.230	283	2.970
Asia	740	32.200	416	18.100	324	14.100
Africa	740	22.300	587	17.700	153	4.600
North America	756	18.300	418	10.100	339	8.180
South America	1600	28.400	910	16.200	685	12.200
Oceania	791	7.080	511	4.570	280	2.510
Antarctica	165	2.310	0	0	165	2.310
Total	**800**	**119.000**	**485**	**72.000**	**315**	**47.000**

* Rebouças, Aldo C. et al. "Aguas dulces em Brasil. São Paulo", Escrituras Editora, 1999

3.1.2 Water in Latin America

Latin America is one of the regions with the greatest wealth in hydric resources, holding 26% of the world's water and only 6% of its population, while in contrast Asia concentrates 30% of available water and 60% of the world's population. Nevertheless, Latin America faces serious issues with respect to water supply: it contains some of the most humid areas on Earth and some of the driest deserts, water sources are polluted to an important degree and in recent decades, the region has been going through intense urbanization. Two thirds of the land in Latin America is arid or semiarid, including great extensions in the center and north of Mexico, northeast Brazil, northwest Argentina, northern Chile and areas in Bolivia and Peru. It is estimated that one fourth of the Latin American population –more than 100 million people– live in areas under water stress, mainly in Mexico, Argentina and the countries located along the western coast of the continent (PNUMA, 1999).

The fact that Latin America is the region with the greatest water availability per capita does not imply that there are no populations suffering from serious water scarcity. The region is becoming more dependent on the use of its groundwater sources: South America obtains 40 to 60% of its water from below the surface, while Central America and Mexico depend 65% on these sources. In Mexico for example, 102 out of 653 aquifers are over-exploited. With a population demanding more basic services and a model for economic development based on the exploitation of raw materials, Latin America is headed towards the worsening of its problems regarding exploitation of its water sources (Tribunal Latinoamericano del Agua).

3.1.3 Water in Argentina

Argentina's water resources are distributed irregularly, two thirds of its territory is arid and semi-arid and only one third is rich in water sources, most of which are surface waters which represent 84% of the available water in the country.

The uncontrolled growth of industrial and productive uses and the untreated wastewater they discharge, together with the disorganized development of important marginal human settlements, have provoked considerable deterioration of hydric resources as a consequence of inadequate exploitation and the dumping or infiltration of all kinds of contaminating substances. This has brought about issues related to the development of aquatic life, increase in the cost of water purification, appearance of water-borne diseases or an increase in their incidence, and a decline in conditions for the development of recreational activities.

Overall, Argentina's average annual hydric supply per inhabitant is greater than 20,000 m^3/inhab., much higher than the threshold for water stress adopted by the UNDP (United Nations Program for Development) of 1,000 m^3/inhab. Nevertheless, in spite of this important water supply and because it is concentrated in the area corresponding to the Rio de la Plata basin, there is a serious imbalance between potential demand and availability in wide regions in the country (Table 2).

In addition to water quantity, it is relevant to consider the quality of available water. In a great part of Argentina, for example, groundwater is affected by high concentrations of arsenic and

Table 2 . Imbalance Between Potential Demand and Availability in Wide Regions in the Country

Region	Problem
Arid and Semi-arid	Water deficit due to scarcity and seasonal variations of supply. Limit to the favorable possibilities for development of agricultural products of high relative value. Conflict due to over-exploitation of aquifers. Loss of productive capacity due to salinization.
Humid and Sub-humid	Decline in water quality due to pollution of surface and groundwaters caused by discharge of untreated wastewaters. High amounts of salts, excess arsenic and fluorine (north and central Pampa regions) or low power in aquifers.

fluorine. Likewise, in the main metropolitan and industrial areas, and particularly in the Metropolitan Area of the city of Buenos Aires (AMBA - Área Metropolitana de la Ciudad de Buenos Aires) there are serious levels of pollution in surface and groundwater resources, which force investment in costly treatment.

In summary, the availability and demand of water resources in Argentina are highly diverse, and in order for the nation to satisfy its potential and desirable uses, it faces important challenges with respect to water management and quality, as well as its spatial and temporal availability. It is necessary to perform analysis and studies that not only consider overall data, but also the variable quantity and quality of water needs and availability in every basin and sub-basin.

3.2 Uses Given to Hydric Resources

3.2.1 Description of the Main Sectors and Activities

Water and Sanitation

During the past century, the use of drinking water increased twice as fast as the number of inhabitants. Nevertheless, it is estimated that 20% of the world's population currently lacks access to water in minimally satisfactory conditions and 50% has no adequate sanitary facilities (WHO, 2008).

International norms established by agencies such as the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) suggest a minimum amount of water per person of 20 liters per day found within a distance of one kilometer from the user's dwelling. This amount is sufficient for drinking and basic personal hygiene. People who lack access to this amount of water are limited in their ability to maintain their well-being and the dignity involved in being clean. The minimal amount of water per person increases to nearly 50 liters a day if water needs for personal and domestic washing are included.

Water consumption varies between 200 and 300 liters per person per day (l/p/d) in most European countries and reaches up to 550 liters per day in some areas in the United States. In contrast, a large portion of the world's population is found extremely below the minimum basic water needs, not just temporarily but permanently. There are 1,100 million people that live more than one kilometer away from a water source and use less than 5 liters of unsafe water (UNPD, 2006). The average use in countries such as Mozambique for example, is less than 10 liters per person per day. People in less developed countries with difficult access to improved water sources tend to consume less water because they must travel long distances to get to the source, or they must pay excessive amounts of money to obtain it.

On a global scale, in 2008 it was estimated that 57% of the world's population had a piped connection within their home or plot and 30% had access to an improve source (tap or public source), thus 87%, or approximately 5.9 million people used clean water or improved sources, which implies an increase of 1,800 million since 1990. However it is worth noting that nearly 1,000 million people lack access to water with minimal conditions of quantity and quality, and if we add families with access to water only through an improved source that does not comply with clean water standards, the number grows to 3,000 million.

In Latin America and the Caribbean, the average piped-water service coverage is 84%, while other improved sources represent 9%. Within the region, Uruguay (98%) and Chile (93%) have the highest coverage rate per network, while Argentina stands at 80%.

Regarding sanitation services worldwide, the average access to improved systems (facilities that guarantee no contact between people and human feces) for the year 2008 was 61%, while 11% used some form of shared sanitation (improved sanitation with shared use of facilities, including public toilets), 11% used non-improved forms (do not guarantee the separation of wastes from human contact) and the remaining 17% resorted to open-air defecation.

In the case of Latin America and the Caribbean, 80% of the population had access to improved sanitation, 14% used non-improved facilities and 6% practiced open-air defecation, while average sanitation coverage by connection to a public network within urban populations in Latin America was 57% (BM, 2009).

Argentine Republic

It is considered that 80% of the population in Argentina has a home connection to a clean water network, and only 47% has a home connection to a network of sanitary sewers; although this percentage increases to 90% if improved sanitation services are included. Only 12% of collected wastewaters are treated before returning them to receiving bodies of water.

It has been calculated that the national average drinking water production per person is 400 liters per day, although it varies widely between one province and another from a maximum of 650 l/p/d in San Juan to a minimum of 170 l/p/d in La Pampa.

Non-revenue water is one of the main problems concerning efficiency in drinking water services. It is estimated that 35 to 40% of the water produced is lost within the network and is under-billed because of clandestine connections and poor updating of user registry. Thus average water consumed in Argentina is estimated at around 250 l/p/d, with maximum rates of up to 400 l/p/d. Compared to many countries in the world and in Latin America, Argentina's high water use can be mostly explained by the low degree to which water use is micro-measured and the prevalence of "free-faucet" type billing in the Argentinian system, especially in the majority of large-city services. In this respect, and according to international records, average consumption of water registered by micro-measurement systems is found generally to be below 200 l/p/d.

Water and Agriculture

Although the global demographic rate is falling, the number of persons that become part of the world's population every year is approximately 75 million. As population increases, hydric resources available per capita become more restricted and it becomes necessary to increase agricultural productivity. In order to satisfy the estimated growth in food demand between 2000 and 2030 in developing countries, a 67% increase in food crop production is anticipated. Likewise, the continuous improvement in productivity should allow an expected 14% growth in agricultural use of water (UN, 2006).

Irrigation consumes most of the water extracted as a result of evaporation processes, passage of water into plant tissues and transpiration in crops. Water that is extracted but not consumed recharges aquifers or evaporates. Globally, more than 65% of extracted water is used for irrigation (FIG. 2).

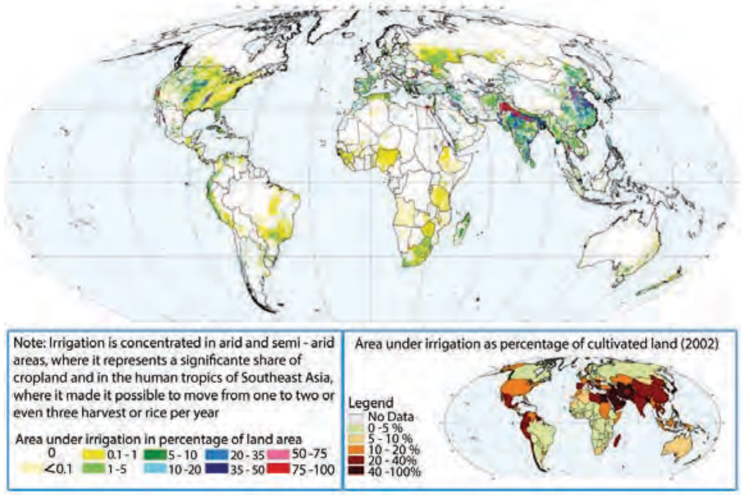
The intensive use of water for agriculture can create great tension on water resources. Fig. 2 shows that close to 20 countries worldwide are in a critical situation, as more than 40% of their renewable hydric resources are assigned to agricultural use. Alternatively, a country is considered to be in a situation of water stress if it uses more than 20% of its hydric resources. According to this criterion, 36 out of 159 countries (23%) suffered water stress in 1998 (FAO,1995).

Both Latin America and Argentina have an average water extraction for irrigation of less than 5% of their total renewable water resources.

Water and Industry

Industry is an important user of water resources and because of its high participation in the gross internal product (GIP) it is the greatest contributor to the economic and social development of nations. To guarantee industrial development, there must be access to an adequate supply of water on the one hand, and a commitment to use water efficiently and not return potentially polluting untreated wastewater to nature on the other.

Depending on the region, the negative impact of industry on aquatic environments is of greater concern than the volume it effectively uses. Water quality is deteriorating in many lakes and rivers worldwide, and the marine environment is also being affected by industrial pollution (UN, 2006). In low to mid-income countries, a large part of industrial activity is accompanied by unnecessarily high levels of water use and pollution. Industrial use of water increases according to the income of a country, varying from 10% in low to mid-income nations, to 59% in countries with high income. In developing countries, an estimated 70% of liquid industrial wastes are discharged



SOURCE: S. SIEBERT 2005

FIG. 2 . Areas Under Irrigation in the World (2000)

into bodies of water (rivers, lakes, oceans) without purifying treatment (UNESCO, 2003). FIG. 3 is a general representation of the distribution of water uses worldwide per low, mid and high income nations.

The annual water volume used by industry is expected to increase from 752 km^3/year (as measured in 1995) to an estimated 1,170 km^3/year for the year 2025, and industrial use is expected to represent 24% of the total fresh water extracted in 2025 (UNESCO, 2003).

Nevertheless, it is possible to separate industrial development from environmental deterioration, radically reduce the use of natural resources and energy and simultaneously have clean and profitable industries. With the proper incentives, it is estimated that industrial water demand can be reduced 40 to 90%, even with the existing techniques and practices. For these purposes water conservation policies that are both fair and feasible are essential. There is a wide variety of instruments (normative, voluntary initiatives, training activities) and consultancy available to help industrial managers improve the productivity of water use and reduce contaminant emissions to extremely low levels. At the same time, these actions can help production efficiency, as well as reduce the use of raw materials, facilitate the recovery of useful substances and promote the growth of reuse and recycling practices.

Water and Energy

The world's hydropower potential is approximately equal to the total energy consumed at present, although only one fourth of this potential is actually used. Consequently to this day, hydropower is an important alternative to the use of fossil fuels. It is estimated that more than 50% of the energy used in 65 countries is hydroelectric, in 32 countries it is 80% and in 13 nations nearly 100% of their energy is supplied by hydroelectricity.

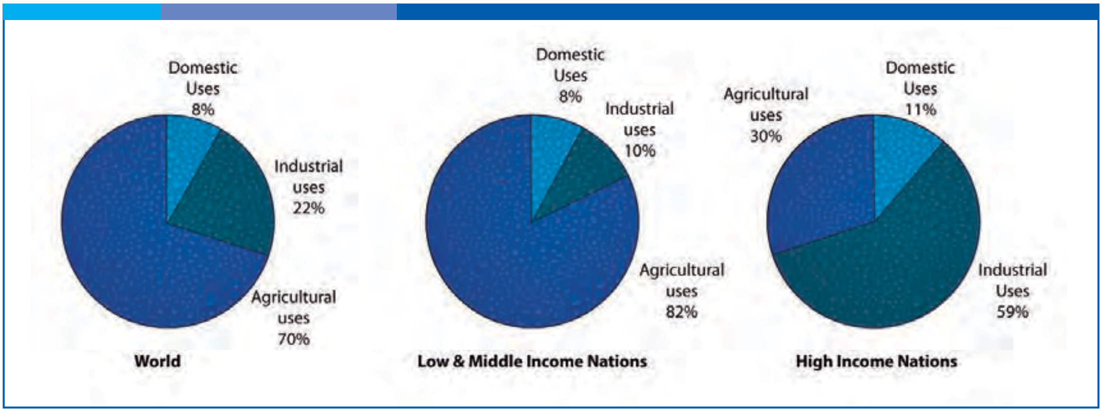


FIG. 3. Water Uses

The fact that 1/3 of the world's population still has no access to electricity is an incentive to consider the alternative of hydroelectricity. However, when potential projects and their design are to be considered, it is vital to contemplate the possible negative impact on the environment of each one and plan to minimize it.

Hydropower is the most widely tested technology for the large scale generation of electricity: it does not contaminate water; does not consume the resource; produces no waste materials and consequently no greenhouse gases; has the highest yield of all technologies (greater than 90%); uses a renewable resource; directly produces mechanical energy instead of heat, can be obtained by means of machines of many different sizes, and generates a group of positive externalities. In addition, investment in hydropower works that are adequately designed and operated allows satisfaction of other water uses, such as irrigation, supply of drinking and industrial water, navigation, fishing, and flood control, as well as recreational and tourist activities. Hydropower implies a very low operating cost, although it requires an important initial investment.

Asia is by far the continent with the greatest hydroelectric resources and the one which maintains the most aggressive policy regarding development of hydroelectricity. Although South America follows Asia, with respect to hydropower resources, they are mostly concentrated in Brazil and are growing much less rapidly. Europe, North America and Australia, in that order, have installed a good part of their potential, while in Africa the development of hydropower is still an unresolved issue, as are many other development indicators.

It must be pointed out that in spite of all the advantages mentioned in the previous paragraph, special attention must be placed on hydropower's negative effect on the environment. This means that the viability of any hydroelectric project must include a very meticulous assessment of environmental impact. If this assessment is positive, it must be complemented with a plan for environmental management that includes the analysis of the entire hydrographic basin involved, and values and conditions the characteristics of the project to guarantee functionality and production within the basin's natural ecosystem.

Other Uses of Water

Water management includes not only the uses of water in human activities, but also the collection of potential uses of water within the natural ecosystem. Thus effective use of water within the water cycle depends on a broad vision, and implies strategic planning including analysis of the needs to be satisfied and optimization of the system.

In order to prevent floods for example, a part of a reservoir's regulatory capacity must be dedicated to buffer the impact of exceptional rises in its level. Such a purpose, "preventing floods", competes with other uses of water assigned to reservoir capacity and is therefore considered another use of water. Likewise, the need to maintain the ecological flow of rivers to preserve their biota and hydrological processes as well as the natural environment, is also considered an effective use of water, because it reduces the availability of water for other uses. Water pollution itself can be considered a consumptive use of the resource as the lack of water quality reduces supply for specific uses.
Other significant and customary uses of water have been fishery, navigation and recreation.

3.2.2. Evolution and Tendencies Observed in the Use of Water.

When first approaching tendencies related to the use of water, it is logical to think that global demand will increase with a growing population, greater income per person and increasing urbanization[1], while the availability of fresh water will remain nearly constant. However, such a viewpoint does not consider human instinct for survival, nor humanity's creativity and adaptability to face similar situations in many other circumstances.

The most well-known example is the pessimistic prediction by Malthus regarding insufficient food production for a rapidly growing population, which was refuted in the following centuries. Such an example helps focus the topic along less simplistic lines, which consider that together with an increase in demand, it is possible to respond adaptively and innovatively, affecting demand as well as efficiency and thus making it possible to convert what nature offers into what man needs, by means of the growing practice of so-called "sustainable technologies".

The use of fresh water in the world has grown six-fold in the past century, while population growth has multiplied by three. According to estimates for the year 2008, 13% of the global population has no access to improved water, a third of the remaining 87% are not connected to a network, while 49% lack improved sanitation (JMP, 2010).

1 "It should be noted that the great urban masses -3 billion people - need large volumes of water for their sustainment; in addition, they produce an enormous amount of wastes (feces and urine) which require immediate treatment to avoid contamination of surface and groundwater. (Added to the needs and consequences of economic activity) this group of problems has led to the current situation affecting water, a crisis never seen before that demands action in the short, mid and long term" (Tundisi, 2009).

Africa and south Asia are the areas with the greatest deficiencies. We could say in summary, that problems concerning water in developed countries affect above all environmental conservation and economic growth potential, while developing countries also have scarcity issues and still lack drinking water, which among other consequences, directly causes diseases such as diarrhea, cholera and others that provoke serious limitations on global growth and cause avoidable deaths.

Irrigation takes on average 70% of extracted fresh water and a significant part of this demand is due to the use of inefficient techniques such as irrigation by flooding. Industrial use on the other hand, is estimated to double in 2050, and in countries under rapid industrialization such as China, it will increase up to five times. Urban consumption increases along with per capita income, especially in relation to recreational uses (sports fields, parks and gardens, etc.) and those related to tourism. In contrast, the decrease in quality of fresh water very seriously affects its availability, as soon as the natural self-purification capacity of rivers is surpassed. In this respect, diffuse contamination from farming practices caused by uncontrolled toxic pesticides and fertilizers produce eutrophication (excessive algal growth and death of aquatic ecosystems) and in many cases can cause cancer due to the high concentrations it reaches in certain countries.

Furthermore, industrial contamination by heavy metals, organic matter and new toxic compounds is estimated to grow by a factor of four in 2025. Urban pollution is present above all in megacities and its slum areas.

Another important problem concerns groundwater, which comprises 97% of the earth's freshwater, in contrast to the almost negligible 0.015% surface water retained in reservoirs. 33% of the world's population depends on these waters, especially in rural areas, nevertheless it is threatened not only by the natural quality of these waters which in many cases are in contact with geological water layers containing arsenic or other harmful substances, but also by anthropic pollution of aquifers or inadequate use of existing wells.

It is important to consider that fresh water is not uniformly distributed from a geographic or time perspective. Uneven distribution has brought about the construction of great reservoirs and diversions, not always considering their social and environmental impact. These factors have led to the fear of possible wars triggered by access to water and to apocalyptic predictions that announce that the XXIst century will be the century of water wars.

3.3 Water Requirements: Minimun and Midsized Levels

Many countries are in negative-balance with respect to water resources because they consume more water than they have at their disposal as a renewable resource. Water deficit is mainly produced when groundwater extraction is greater than aquifer recharge. This causes exhaustion of the resource, and in certain arid nations that base a substantial amount of their development on water, it is destabilizing. It has been estimated that in the main water over-drawn countries nearly 160 km^3 of water are exploited annually, meaning that 180 million tons of grain (10% of the world's production) are being produced with non-renewable hydric resources.

If the current levels of water consumption continue, two out of every three people on the planet will be living in water deficit or hydric stress –moderate to severe water scarcity- by the year 2025. At that time, it is probable that at least one in four individuals will live in a country affected by chronic or recurrent fresh water scarcity (FIG. 4.).

As mentioned above, as the world's population has been tripling in the past century, water use has doubled, and therefore consumption has grown six-fold during this period. The world's population is expected to increase from nearly seven billion people in 2010 (6,903,100,000 United States Census Bureau), to eight billion in 2025. At the same time, the World Water Commission predicts that water use will double in thirty years.

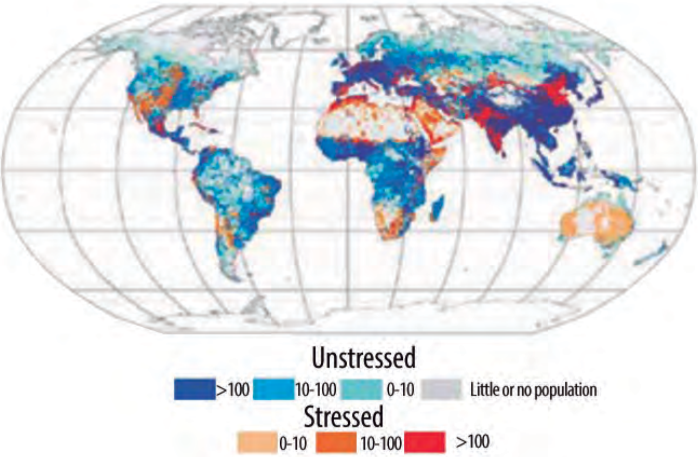
4. Emerging Water - Related Issues

4.1 Water and Basic Human Needs

4.1.1 Access to Water as a Human Right

The definition of human rights was determined at the end of World War II to indicate the rights that every human being is entitled to, inherent to the status of being human and opposable to all other human beings and States. The right every human being has to water arises from the fact that life is impossible without it, and thus it is a natural right inherent to life. This implies that the right to water is not created by legal regulations, but rather these norms recognize and protect it, and that it can and must be exercised even when not imposed by a statutory norm. Therefore, the right to water is indisputably a natural and human right.

On the other hand, it is important to consider the harm caused by the lack of immediate access to clean water and the way this affects the unproductive time invested in fetching it, and the cost of water-borne diseases and their impact on infant mortality and labor dynamics.



SOURCE: UN, 2003

FIG. 4. Population above and below the Threshold of Hydric Stress.

4.1.2 Water Supply and Sanitation

The percentage of the population covered by residential water and sanitation services per region is shown in Table 3. Sub-Saharan Africa can be seen here as the area with least urban water supply, followed by South Asia.

Tariff and Costs Coverage

The value and structure of fees are among the main factors determining sustainability of water and sanitation services. These factors determine how capable the service is to cover the costs of supply by means of self-generated income or funding from other sources. According to a study by Global Water Intelligence (GWI) and based on water services in important cities worldwide, it is normal practice to fix the price of clean water services below the supply cost. The average tariff based on a residential consumption of 15 m^3/month is US$0.53/$m^3$ and increases with national income level.

Based on a sample of companies from around the world, it was calculated that in 30%, fee income covered operation and maintenance costs (O&M) and partially covered costs of capital (C), while in 39% fee income was not enough to cover O&M. This percentage however, changes with national level of income. In low income countries, only 3% of the companies had fees that covered O&M and part of C costs, while in 89%, fees were too low to cover O&M costs. In low to mid-income countries, 22% covered O&M and some of C costs and 37% did not cover O&M costs. In Latin America and the Caribbean, 48% covered O&M and some of C costs, while 13% were unable to cover O&M costs with their fees (Fay, 2006). Currently in Argentina, several services in large cities cannot cover O&M costs with fee income.

Subsidizing drinking water services is more the norm than an exception within the sector. In some cases this is a consequence of fixing tariffs for the service according to political criteria instead of the costs that guarantee sustainability.

On the other hand, many countries have taken pains to develop tariff schemes that allow service sustainability, along with parallel subsidy schemes focusing on the needs of poorer homes that are unable to pay these fees. Thus they achieve both the financial goal of self-sustainability of the service and

Table 3. Percentage of Population Covered by Water and Sanitation per Region– Year 2008

Region	Home Water Supply	Urban Water Supply	Rural Water Supply	Urban Sanitation	Rural Sanitation
East Asia	15	83	49	61	53
Southeast Asia	33	92	81	79	60
South Asia	23	95	83	57	26
Sub-Saharan Africa	16	83	47	44	24
North Africa	92	96	78	94	83
Developed Countries	94	100	98	100	96
Latin America	84	97	80	86	55

Source: JMP (2010). Joint Monitoring Program (WHO+UNICEF). Information corresponds to 2008. Names and definitions of type of access to water services and sanitation correspond to those established by the Joint Monitoring Program in its documents.

the social goal of universal coverage. State participation for financing infrastructure is also common at several jurisdictional levels, particularly in major building projects.

In order to achieve financial sustainability of services, it has been deemed convenient that tariff income should cover at least operation costs and those related to infrastructure maintenance so as to guarantee service quality and the state of conservation and functionality that corresponds to the recommended technical standards.

4.1.3 Water and Health

Every year, diseases related to water cause more than 5 million deaths worldwide, while approximately 2,300 million people suffer from water-borne diseases and 60% of infant mortality is caused by infectious and parasitic diseases, most of them related to water. Diarrhea is one of the main causes of death in these diseases.

The relation between GIP per capita and the number of deaths or illnesses caused by the consumption of unsafe water, lack of adequate sanitary conditions and poor hygiene reveals, that the most serious problems regarding water-borne diseases are found in poorer countries.

Universal clean water and sanitation services not only improve the health of the lower income population but also their income through cost reduction of these services. Improvement also occurs in the general well-being of families as it implies progressive distribution of income. In the developing world, it has been calculated that 80% of all diseases are due to consumption on "non-drinkable" water and the poor sanitary conditions of the population. Close to 20% of all illnesses could be avoided by improving water supply, sanitation services, and hygiene and handling of water resources (UNESCO, 2003). Additionally, these improvements would reduce infant mortality and nutritional level in a sustained manner.

Water supply and sanitation services also improve education as school attendance increases when absences caused by disease or time dedicated to carry water is reduced. Women are especially affected by fetching water (UNPD, 2006). Within the domestic scope, emphasis is made on the lack of access to sufficient quantities of drinking water and adequate sanitation, as well as the promotion of good hygiene habits.

4.2 Water and Development

4.2.1 Regionality

Water is the most important component on the planet and all living things depend on its presence. Water also promotes or discourages economic growth and social development in every region and affects its life and cultural patterns. Therefore water is recognized as the predominant agent in regional and national development.

From primitive urban and farming settlements, the development of peoples has historically been closely linked to water, becoming a decisive factor in the selection of a place to live and to locate all kinds of industrial plants. Demographic and economic growth, lack of criteria for conservation and sustainable use of natural resources, subsequent pollution and regional growth of water demand have all contributed to its scarcity. This has led to competition for the resource, which becomes acute during dry years and culminates in conflicts that affect the development of communities. Thus the control, rational use, and preservation of water quantity and quality within national, regional and local spheres are strategic for the development of nations and the protection of human beings.

Total consumption of water tripled between 1950 and 1995, when water use exceeded 4,300 km^3/year or the equivalent of 30% of the world's stable renewable water supply. In addition, the world's irrigated surface has increased five-fold to be able to feed its population; consequently, more than 26 countries have had their water availability fall below 1,000 m^3 per person per year, reaching water scarcity. This reveals a global scene of poor water management, scarcity, over-exploitation and pollution that is reaching a point where water is becoming the limiting factor for sustainable development in many nations.

On the other hand, in many countries the problem is not the lack of fresh water but its poor distribution. In general, large countries often have significant differences in regional development. Argentina is not foreign to this phenomenon and along its extension there is great territorial inequality. In spite of its important overall water supply, there is a large imbalance between potential demand and availability in large areas of the country. In the humid and sub-humid regions, where water supply and climate characteristics allow the growing of crops on un-irrigated land or by supplemental irrigation, the deterioration of water quality has put increasingly severe limits on water availability. These regions are where the most important human settlements are found together with areas of strong industrial development.

4.2.2 Seasonality

It is important to consider the seasonality of hydric resources and its connection to potential regional growth. Most time-series for hydrologic variables have an important seasonal component. From a hydrological viewpoint, greater seasonality is linked to greater precipitation in certain months of the year, which is directly associated with the rainfall pattern and occasionally, in basins fed by snowmelt or both rain and snowmelt, with the presence and orientation of mountain ranges, i.e. orography. Precipitation seasonality is often a factor that restricts the use of water, in particular when supply and demand are out of step, although this can be reduced by regulating water through reservoirs.

Ultimately, water seasonality is an additional restriction to the amount of water economically available and it can be very severe. When seasonality and availability are considered together, they allow "hydric stress" indicators to be determined when compared relative to demand.

4.3 Water and Society

4.3.1 Giving Value to Water

To recognize that water is a good with economic value implies understanding the need to apply economic principles to its study and the organization of its use, for the purpose of achieving its proper management and administration. This does not necessarily mean that a price must be put on water; it implies that its management must consider both direct and indirect social and environmental costs and benefits associated to its various uses and include the restrictions these have in order to protect the health and safety of individuals and the environment.

Incorrect allocation of costs for example, has contributed in many cases to resource and environmental deterioration. If only the costs declared by users are considered, or those determined by partial interests, and all the costs that are effectively paid for by society as one are excluded, the use of the resource will not be sustainable.

Integrated management is an alternative to the market system which allows the weighing of all benefits and costs that a society faces when adequately managing hydric resources. This means achieving the participation of all of the affected sectors in the making of important decisions. This mechanism cannot guarantee that optimum decisions will be reached, although it can ensure that they will be based on the coordinated efforts between all those affected by interrelationships that cannot be resolved by operations research tools and systems analysis, because of their complexity.

The main reason why it is difficult to organize water markets is that water is not a homogenous good, as it continuously changes in most of the processes related to its use, quality and location.

4.3.2 The Issue of Water in Education

The XXIst century is destined to be "the century of water", and we have already warned that the future of the development of nations is strongly linked to water and its availability. However, there is clearly a lack of integration between water management and society's interests, attitudes and behaviors regarding water; therefore it is necessary to radically transform current practices, in other words, it is necessary to develop a new water culture.

Responsible participation of social actors in the management of water requires an irreplaceable ingredient: that they understand the processes. In this way it would be possible to facilitate agreements to execute rational, responsible and supportive actions in every one of the tasks in which these actors must interact with water, making special emphasis on providing value and grassroots support for the conservation and responsible use of water as a resource for life.

4.3.3 Public Participation in the Water Management

The movement towards a new relationship with water based on sustainability not only requires continuous economic, scientific and technological efforts, but also new approaches in the field of education, as well as a reconsideration of the processes used to facilitate individual participation in the making of public decisions. As individuals participate, there is an improvement in the efficiency with which human societies respond to the challenges of the environment and sustainability. Intervention by the people permits a better diagnosis of existing problems, the generation of a group of wider alternatives to solve the challenges proposed, and the mobilization of the human and material resources of various social participants, to achieve better management of the environment. Frequently, the appropriate solution to a problem is found exclusively in the hands of the community itself, thus making its participation essential (IV Congreso Ibérico, 2004).

Participation does not guarantee that everyone will agree with the decisions adopted in the end, but it can promote taking the desires and needs of a large number of people into account, and in this way participation integrates interests into the decision-making processes. In addition, it allows people to better understand the reasons behind a decision, the complex variables that affect problematic issues, the potential effects that must be foreseen when getting involved or the limitations that condition decision-making.

The following are some of the more specific arguments that show the need for participative decision-making:

- River basins are synergic: any action taking place in one point affects the whole. Users and residents in a basin must share and resolve the tension generated by the use of water.
- The characteristics of water are irregular; this forces the making of unforeseen decisions, and therefore decision-making based on rigid and predetermined formulas becomes inadequate.

Traditional conceptions regarding the process of development must be overcome. Community participation must include analysis, decision-making and action. Therefore, activities must focus on information, education, seeking advice, strengthening initiatives, taxing, agreement, decision-making and management in all phases of the project. Education on the use and management of water must be available to all; nevertheless, it must adopt diverse formulas that are adapted to a variety of recipients and socio-environmental contexts. Education must be permanent, universal and go beyond generation boundaries so as to reach the education system, as well as administrative and social actors.

Although there is a wide group of useful instruments to organize and channel public participation in environmental management, a very limited set of instruments have traditionally been used to plan and manage water (IV Congreso Ibérico, 2006). They have been questioned in the following areas:

- Lack of information about procedures: data regarding procedures (deadlines for claims, places to consult documents, etc.) do not always get to those potentially interested because the information is frequently published only in the official journal and there is no real effort to disclose it further.
- The complexity of the documents at public disposal: the highly technical character of the documents at public disposal makes it difficult for those interested to interpret them.
- Lack of transparency: it is uncommon for social actors to have access to sufficient information regarding water as to guarantee the transparency of the processes involved in its management.

An additional reason to promote participation is that the only way to have been proved by experience that effectively avoids management from being dominated by partial interests in the absence of competition as a control-mechanism, is the demand by citizens through tools that channel participation efficiently.

4.3.4 Interjurisdictional Hydric Resources[2]

It has been calculated that for the year 2025 water demand will be 56% greater than supply. In fact, it is already a scarce good for a good part of humanity: more than 20% have no access to clean/safe water (2.6 billion people according to the WHO and UNICEF) and up to 40% suffer its scarcity and cannot even count on basic hygiene infrastructure in their homes. Conflicts have started to appear regarding global appropriation of local hydric resources either by reservoirs, channels, tanks or bottles.

In 1949 there were 5,000 great hydraulic dams on earth and at the end of the XXth century the number had increases to 45,000. Because many of these dams modify the flow of rivers that are shared by several countries, they have sparked conflicts in many cases.

The conflicts that have arisen between Egypt and Ethiopia for the exploitation of the Nile River are well known, as well as those in the Democratic Republic of Congo as a consequence of the Grand Inga dam or in the Brazilian Amazon where indigenous peoples fight against the Xingú River dam. To these confrontations between peoples and nations we can add the violent protests in cities such as Cochabamba (Bolivia), Soweto (South Africa) or Jakarta (Indonesia) against the privatization of water supply and everything seems to indicate that there will be more of these situations because of the growing pressure of demand on available resources. There are places where water costs account for 10% of the income of poorer families.

Problems that cause insufficient water supply typically go beyond community and political boundaries and affect continents and countries. Many political limits between countries are bodies of water; close to 40% of the global population lives in river basins that are shared by more than one country, and many communities (such as Israel and Palestine) depend on drinking water from the same aquifers that have been over-exploited. Thus water scarcity resulting from its poor management frequently brings about the risk for conflict. This is why it is so important to find ways to manage shared water by means of cooperation without confrontation. In summary, proper water management, according to its characteristics, requires not only local but also national, regional or international action.

Argentine Republic

The Constitution of the Argentine Nation has established that provinces have the original domain over the natural resources that exist in their territories, which means that provinces own their hydric resources. Whenever water is shared by several provinces, agreements must be sought between the parties. Basin committees have been created to facilitate these agreements and in some cases basin agencies with executive powers (See Appendices, points 6 and 7).

2 Point 6 (Appendix I) deals with the topics introduced here

4.4 Significant Impact Related to the Water Sector

4.4.1 Droughts and Floods

The definition of drought has been highly debated because of the disparity in the criteria applied by various authors. It has no universally accepted definition and therefore has becomes a term that is not entirely precise. In its broadest meaning, a drought may be an abnormal period of high water scarcity produced by a lack of precipitation with negative effects not only agriculture but also on other activities such as hydroelectricity, and drinking water supply as well[3].

Of all natural disasters, droughts have the greatest economic impact and affect the largest number of people.

Floods, as well as earthquakes and cyclones, may have a great physical intensity but they do not last long and have a limited geographical impact, although the number of deaths caused by these disasters may be very high if densely populated areas are affected. In contrast, droughts affect large extensions of territory, including entire countries and can last several months or in some cases even years.

Disasters caused by flooding account for one third of all natural disasters around the world, at least in terms of economic loss, and are responsible for more than half the fatalities. Damage by floods has been extremely severe in the past decades and their intensity and frequency have been clearly increasing. In the past ten years, losses have reached more than 250 billion dollars.

Floods have also caused numerous human deaths. The list of natural events that have caused human victims in the last thirty years includes two great flood disasters, in 1970 and 1991, both in Bangladesh. They respectively occupy first and third place regarding number of victims. Fortunately, the number of flood fatalities tends to decrease in time because most exceptional hydrologic events develop slowly and forecast techniques and early alert systems have been implemented in many densely populated areas.

As to economic losses, the situation remains serious because not only have great disasters increased in number, but annual losses also consider minor events that produce local flooding. A tendency analysis reveals that flooding disasters and the economic losses they produce have drastically increased in recent years. Additionally, economic costs of floods must consider the cost of building structures against floods and their maintenance.

4.4.2 The Effects of Climate Change

Any regional increase in extreme events (storms, floods, cyclones, droughts, etc.) associated to climate change will cause physical damage, migration, adverse effects on food production, damage to the quality and availability of fresh water, and an increase in the risk of epidemics

3 "There is no single solution to face the pressure on the growing consumption of water and instability of rain patterns. Nations must draw up holistic action plans and put them into practice." These plans must "guarantee drinking water and sanitation for all/Increase water efficiency in agriculture/Increase anticipation of droughts by means of improving water storage" (Sachs, 2008, p. 184)

caused by infectious diseases, particularly in vulnerable populations.

The precise effect of climate change on hydric resources is unknown. Precipitation will probably increase at latitudes beyond 30°N and 30°S, but many tropical and subtropical regions will potentially receive a smaller or more irregular amount of rainfall. A noticeable tendency towards an increase in extreme meteorological conditions will probably lead to more floods, droughts, mud slides, typhoons and cyclones. If the current situation is not modified, climate change will have more significant environmental, social and economic impact and costs. Such negative impact includes:

- Food security: if global temperatures rise significantly, the most probable effect will be a general decrease in crop production in most tropical and subtropical countries. Arid land could be the most affected, because its vegetation is sensitive to small changes in climate.
- Extreme events: droughts and floods will become more intense. Strong precipitation will cause more damage due to more frequent landslides and avalanches. Some coastal cities will be threatened by flooding.
- Health: tropical diseases will be found at ever higher latitudes. Disease vectors, such as mosquitoes and water-borne pathogens (related to poor water quality, and food availability and quality) will be subject to change.
- Ecosystems: while some species will increase in abundance or variety, climate change will increase the existing risk of extinction in more vulnerable species, producing loss in biodiversity.

It is worth mentioning that the effects of climate change will not be linked exclusively to potential damage and loss to society. It also may produce benefits by improving environmental conditions in specific regions, for example, generating new areas apt for food production at high latitudes or allowing the application of adaptive measures in certain regions suffering modification in their climate which will be better than the current situation.

4.4.3 Water Pollution

Although within the developing world the total population is on the rise, its rural population is expected to decline slightly while its urban population grows rapidly. Human settlements contaminate resources, therefore the proper management of clean and wastewater is essential to reduce pollution and minimize health risks.

Irrigated farming also has a significant impact on the environment. Extraction of water from rivers and lakes for irrigation puts aquatic ecosystems at risk causing losses in productivity and biodiversity. Chemical products used on irrigated land often contaminate surface and underground runoff. Potassium and nitrogen applied as fertilizers can be leached into surface and groundwaters making algae proliferate and causing eutrophication. Irrigation waters can also contain naturally existing salts, and in arid regions, irrigation can leach toxic elements that are natural components of soil such as selenium.

Together with agricultural and municipal wastewaters, industrial wastes put hydric resources at risk throughout the entire planet, harming and destroying ecosystems. This threatens the hydric security of individuals and of the activities that use and consume water. At the same time, pollution has a direct economic impact on fishing and industries that require clean water in both developed and developing countries. Hydric security has been increasingly affected by water deficit and the decline in water quality.

The main problems and processes related to the pollution of surface waters (lakes, rivers and reservoirs) are shown in FIG. 5., taken from Tundisi, 2009.

4.5 Management of Hydric Resources

4.5.1 Emerging Paradigms in the Management of Water

Throughout history and the spreading of the civilized world, water has been managed in very diverse ways. Nevertheless, within this highly varied landscape, it is possible to observe the permanent presence of tension along two lines: between centralized and decentralized forms of organization, and between a greater or lesser participation of private initiative.

The fact is underlined by the paradigm that has been taking shape in recent decades which proposes that going from one of these extremes to another, a frequent situation

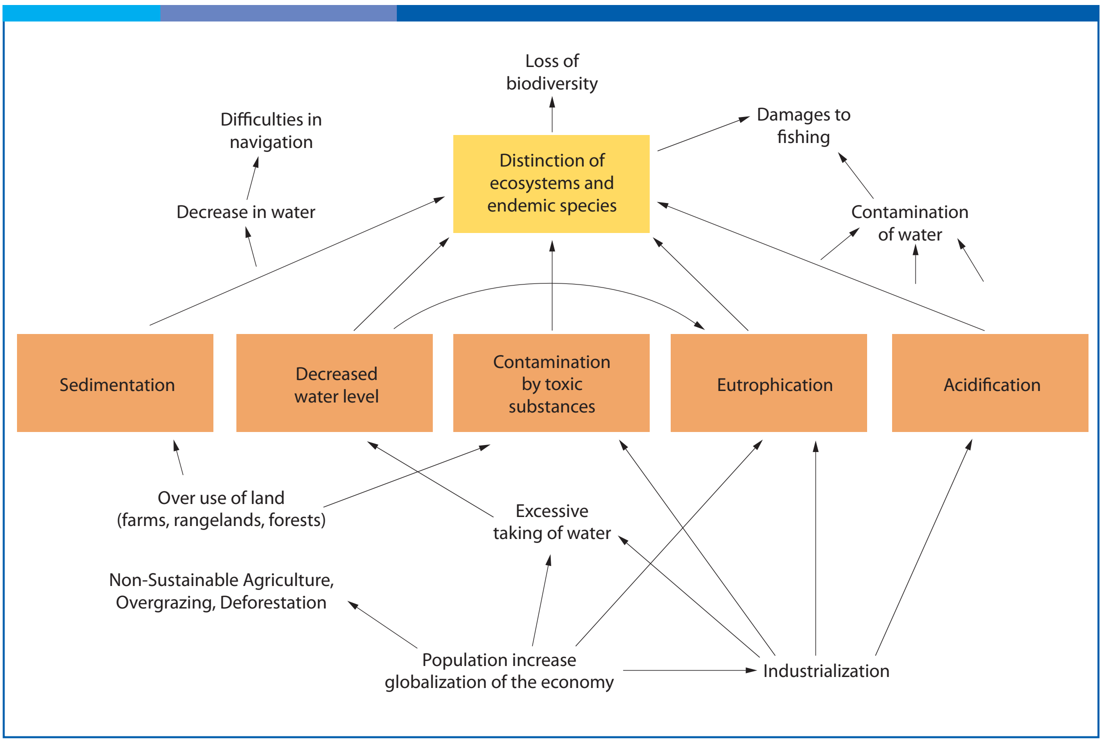


FIG. 5. Main Problems and Processes Related to the Pollution of Surface Water (Lakes, Rivers, Dams). Results of the Study Carried Out in 600 Lakes of Several Continents by ILEC.

in many countries, reflects the need to attain a balance between opposite forms of organization, as no extreme form can produce good results on its own. The Dublin Principles[4], reached by consensus in 1992, propose this paradigm in a language that is accessible to those who are non-specialists in the many areas that are relevant for water management (basically engineering, geology, meteorology, biology, law, economics and public and private management).

"How can there be a balance between purely technological management and management that includes education, divulging of problems and community participation? The issue should be considered for each basin or sub-basin and shall depend on the degree of existing technology and the perception and education of the community, as well as the ability of decision-makers, municipal prefects and basin managers to manage conflict" (Tundisi, 2005).

The Dublin Principles synthesize a consensus on the need for a comprehensive picture on hydric resources, yet this does not imply ignoring or not valuing the opinion of representatives of various organizations, groups of citizens, and local municipal or communal governments. They also reveal an agreement on the need to bear in mind that water has a cost and a value, which leads to consider how private initiative could contribute to its more efficient use.

This new paradigm is to some extent a return to what prevailed in most countries previous to the overwhelming impact of progress made during the XIXth and XXth centuries in the fields of engineering (particularly systems analysis) and economics. Development in these two fields promoted the opposite tendencies mentioned above: towards planned and centralized management of water on the one hand, and towards decentralized management on the other.

The first tendency produced the setting up of Basin Authorities for the purpose of managing hydric resources as a system in which optimum use is achieved by a series of norms and works, on the base of comprehensive assessment of needs and possibilities. The second tendency produced awareness of water as a scarce good, as well as awareness of the convenience of recurring to decentralization (as far as possible given the characteristics of the hydrologic cycle), based on market mechanisms in which individual responses to prices determined by supply-demand interactions define how water is assigned among users.

4 Dublin Principles: 1) Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment. It must be managed in an integrated manner. 2) Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels. 3) Women play a central part in provision, management and safeguarding water. 4) Water has an economic value in all of its competing uses and should be recognized as an economic good, by means of principles that permit accessible cost and socially equitable consumption. These principles were agreed in 1992 during the International Conference for Water and the Environment in Dublin, in preparation for the United Nations International Conference for Water and the Environment held in Rio de Janeiro in the same year.

Both proposals were applied throughout the world, generally producing results that did not meet the expectations they had created. It is now generally accepted that Basin Authorities can only be efficient when there is a very high degree of trust between the independent institutional or political units they are made of, which expressly allows delegation of duties. If trust is not achieved, then conflict over competence results and the execution of the actions proposed by those authorities is jammed (except in poorly developed regions where local government agencies are very weak).

Later there was a revaluation of the traditional organization of water that was based on respecting independence as much as possible and the search for agreements between autonomous jurisdictions that were related by water in various ways. Although it is not always possible to reach agreements, experience shows that for every conflict between independent entities, it is possible to find many cases of amicable solution where cooperation has allowed the achievement of better results than management that only avoids conflict.

Research by the University of Oregon in the United States has found evidence of the low probability of wars sparked by conflict related to water. The study of 263 transboundary basins, spanning close to half of the earth's surface, found that these basins create cooperation more often than conflict. Throughout the past century, 400 treaties regarding the use of rivers have been signed. Out of 37 incidents that have created violent situations in the past, 30 occurred in the dry and conflictive region formed by Israel and its neighbors where the use of the Jordan River was disputed until 1967 when Israel included it in its territory. The study shows agreements between states that are very robust, and quotes the treaty between India and Pakistan that was sustained in spite of two wars and an acute crisis in 2002.

4.5.2 Economics and Water Management

The general objective of the Integrated Management of Water Resources (IMWR) is accepted to be the promotion of efficient, fair and sustainable use of water. The issues considered in the above section regarding the difficulties to attain these objectives by merely applying quantitative techniques or pricing systems, led to the suggestion of minimizing the cost of complying with a series of thresholds or goals related to the main risks facing water management. Because these risks are interrelated in many ways and therefore form a complex system, minimizing the cost of respecting these thresholds or goals is not equal to minimizing the cost of water nor is it the same as maximizing the value of services related to water management.

There is a unique solution to the challenge of achieving efficiency –an efficient use of scarce resources- and efficacy –assigning resources to activities that the population values or needs- without resorting to a pricing system (market) or to quantitative optimization techniques: facilitating coordination and stimulating mechanisms for participatory control. In other words, when it is not possible to organize management in a way that market competition contributes to an efficient and effective assignment of resources, only the demands of the population –as users or clients for the services, or as owners or residents in independent jurisdictions- can promote water management that is efficient and effective.

For this reason, when awareness of the importance to conserve water resources and protect the environment spread throughout all nations in the second half of the XXth century, the new agencies created to achieve these objectives were basically directed to implementing the two lines of action just mentioned: facilitate coordination and promote participation.

In all issues related to defining and reaching the thresholds and goals that minimize environmental and water-related risks there must be coordination between the existing public agencies and also between these and the private sector. The new agencies that manage water and the environment cannot exercise authority over sectoral agencies or autonomous governments on which they depend; they can only promote and enable the success of the numerous agreements needed for integrated water management by providing technical assistance, fomenting the production and diffusion of information on water, and stimulating training and education for specialists in the most important aspects of water management.

Because participation usually is efficient only within the local sphere, it is advisable that basic water services, that is, water supply and sanitation, flood prevention, control of groundwater use, pollution prevention, include participation at that level. In order not to lose sight of economies of scale and other aspects that can only be appreciated from an overall perspective however, local management must be articulated with neighboring jurisdictions, provincial management and national agencies.

Basin Committees are the most widely used coordination mechanism in Argentina, although integrated management needs other additional tools, such as organizing consortia or formulating sectoral interjurisdictional plans.

4.5.3 Water and the Media

A debate on "water and the media" was included in the presentations that took place within the "Water Tribune" in the 2008 Expo Zaragoza, as part of the chapter called "Water and Society"; from it several conclusions and experiences can be obtained.

One particularly interesting topic included the results of a survey on the participation of Spanish television news broadcasts in issues related to water. In general, results show that 74% of the population is informed by television newscasts. Out of four thousand news items commented in four newscasts during two months, only 3.8% were somehow related to water issues. Within this small total, 32% of the news referred to rains, 20% to floods, 28.6% to problems regarding the ocean, 11.3% to droughts and only 8% to water resource management. According to the information presented, newscasts show a catastrophic image of water, as well as one within the frame of the environmental health of oceans. In contrast, they show little interest in technological, economic, social and political issues related to water management.

Although in Argentina there is no statistical information similar to that of Spain, most of the Argentinian population also obtains its news from television broadcasts, with the additional problem that they are seen as showing "the absolute truth".

On the other hand, it is clear that television journalism in Argentina is even more interested in catastrophes because they have more rating, and with exceptions, it has a tendency to look for guilty parties when searching for the technical reasons and eventual solutions to problems. Furthermore, these telecasts show the opinion of a specialized professional that is generally questioned by professionals from other fields, the journalists themselves and supposedly qualified persons. Nevertheless, in most cases it is incorrect to believe that everything is a conspiracy against the specialists in the sector. It must be recognized that specialists have had a relatively poor ability to announce the implications, benefits and eventual problems of their projects in due time and manner. This implies that the education of professionals in the science of water must not only concentrate on the scientific and technological excellence of its graduates but must also search for the adequate methodology to allow its students to transmit the need to give priority to projects within the interests of society and voice its benefits, costs and impact in a simple and credible way.

4.5.4 Institutional Development for Water Management[5]

Water management includes services provided directly or indirectly to individual clients or users, services provided simultaneously to many sectors, such as planning, flood prevention or water conservation, and management regarding coordination between all utilities and between these and other social organization sectors. The services are generally provided by public companies or agencies, within a framework of norms that regulate the activities they must fulfill to reach their objectives. Usually, each company or organization should execute a series of functions within its organization, by agreement with other agencies or through subcontracting.

The fact that almost all of these functions, with the exception of coordination, internal control and updating of the regulatory framework, can be delegated to third parties, helps to understand why water management differs so much between jurisdictions; in many cases several of these functions are provided by specialized agencies, which results in advantages and disadvantages that must be assessed in each individual case.

It is common for several agencies to offer the same services in the three levels of government, so coordination between them is deemed to avoid duplication of their functions. This suggests that good coordination is the key, as it always leads to improved results. It is also important to realize that coordination is just as important within each agency, i.e. among its functional divisions, as it is with other agencies.

In certain cases, reorganization is used to revive organizations that have become

5 Point 7 (Appendix II) describes the legal-administrative framework for water in Argentina.

paralyzed. Nevertheless, reorganization processes cannot usually be used to correct management errors because these are generally the result of not achieving a minimum degree of coordination.

The chapter on "Providing Water and Sanitation" in the book by UNESCO on engineering (UNESCO, 2010), concludes by saying that there is an urgent need for planned action to administer hydric resources and that a particular concern exists for problems arising in urban areas of developing countries (page 287). It points out that many interventions have failed because little attention has been paid to the institutional view that has put them into practice and because of the lack of participation of those involved in their development and execution. It also states: "Intervention must consider the complete urban cycle of water and recognize the interactions between the various components of the system.
Thought must also be given to the way water is used and reused and to greater use of natural treatment systems", in order to obtain more robust and resilient systems in the face of non-foreseeable pressures and emerging pollutants.

5. Hydric Resources in Argentina

Having presented water issues in the context of the world, Latin America and the Caribbean, including some Argentinian references, the present work now discusses information, conclusions and suggestions in three different categories with particular focus on the use of water in Argentina:

1. Posture of Argentina regarding the various uses of water.
2. The challenges of water management in Argentina.
3. Proposals for the development of water resources in two priority areas: energy and water supply and sanitation.

5.1 The View of Argentina Regarding the Various Uses of Water

The following general conclusions can be reached based on the information revealed in the present work including years 2008, 2009 and 2010:

5.1.1 Available Water Resources: Variability Related to Space, Time and Water Quality

- Water supply is irregularly distributed around the world. Latin America and the Caribbean occupy approximately 15% of the surface of the planet and produce 33% of the world's surface runoff. The region is home to 10% of world population and thus the amount of water per person is greater than the worldwide average. However, two thirds of the territory is arid or semi-arid and one fourth of the population lives in areas under hydric stress. Thus, improving the spatial and temporal distribution of water supply and demand is a regional challenge.
- In the past 50 years, global population has tripled while water use has increased six-fold. Water demand for consumption increases as the population grows and improves its standard of living.
- Argentina has an average annual surface water supply greater than 20,000 m^3/person, making it a country rich in water. Nevertheless, the nation's possibilities for balanced territorial development are linked to adequate water availability regarding

space and time, for which it must build infrastructure and management capacity to overcome its climate diversity as well as the uneven distribution of its hydric resources (point 3.1.3).

The humid region is home to 70% of the population (40 inhab./km^2) has a surface of 665,000 km^2 (24% of the total surface area) and a precipitation of more than 800 mm; in addition it holds 80% of agricultural production value and 85% of industrial activity, as well as the essential service infrastructure in the country. Agriculture is mainly un-irrigated, although in the past two decades there has been a strong development of complementary irrigation.
Twenty-eight percent of the population lives in the semi-arid region (15% of the total surface of the country). Because of the significant water deficit in the region during most of the year, irrigation is vital for the development of certain crops.

The arid region (61% of the nation's total surface) is home to 6% of the Argentinian population. As agriculture requires comprehensive irrigation, the development of this area depends on water availability and the adequateness of the soil.

From this information it can be gathered that 76% of the national territory has arid and semi-arid conditions, which emphasizes the importance of integrated and sustainable management of hydric resources (Table 4).

In arid and semi-arid regions, water deficit due to scarcity and seasonal variability limits the production potential of the soil, while in the humid and sub-humid regions, where water supply and climate allow the development of non-irrigated or complementary irrigated crops, degradation of water quality limits its availability.

Table 4. Climatic Regions

Climate Regions	% of total national surface area	% total national population
Humid	24 %	68 %
Semi-arid	15 %	26 %
Arid	61 %	6 %

The average annual precipitation in Argentina is 600 mm, corresponding to an annual volume of 1.668 km^3. Of this amount, close to 83% is evapotranspired and directly evaporated, and therefore annual internal renewable hydric resources by rainfall are calculated at 814 km^3/year. Of this total, 538 km^3/year are contributed by bordering countries, especially the basins of the Paraná-Paraguay and Uruguay rivers.

The total use of renewable hydric resources in the country is 4%.

The country's orographic layout determines the formation of three hydrographic watersheds: Atlantic, Pacific and Endorheic Basins. These greater watersheds are also subdivided into systems and hydrographic basins (FIG. 6.).

The following table (Table 5) shows average annual flow for the most important basins in Argentina. The outflow of the Río de la Plata

SURCE: GIRAUT, GAVIÑO NOVILLO, LUDUEÑA, 1997

FIG. 6. Watersheds and Surface Water Regions

basin represents more than 85% of the total surface resources.

From the perspective of relative hydric wealth, the Pacific watershed systems have the greatest specific flow reaching close to 36.2 $l/sec/km^2$, by far higher than the national average of 6.4 $l/sec/km^2$. Several areas in the arid and semiarid regions, which comprise nearly 15% of the total surface, have basins that do not spill into the sea and their contribution to flow is less than 1%.

Regarding availability of groundwaters, their use is related to rainfall and river water in each region; thus they are used when surface waters are not available. Groundwater supply is limited at times by poor quality and aquifer thickness.

In general, total water supply in Argentina is increasingly conditioned by pollution in rivers, lakes and aquifers from diffuse and concentrated sources.

Influence of Climate Tendencies Observed in the Argentine Republic

- Increase in average annual precipitation in nearly all of Argentina, especially in the Northeast and to the west of the traditional humid region.
- Increase in the frequency of extreme precipitation in a large part of the east and center of the country.
- Increase in temperature in the mountainous area of Patagonia and Cuyo, along with glacier retreat.
- Increase in river flow and flood frequency throughout the country except in San Juan, Mendoza, Comahue and the north of Patagonia.

Based on reports by IPCC, global climate change will increase or create the following sources of vulnerability:

- Flow withdrawal in the rivers of the Río de la Plata Basin.
- Increased water stress in all of the nation's north and part of the west.
- Decreased snow precipitation in the Andes Mountains, probable water crisis in Mendoza and San Juan, as well as a decrease in hydroelectricity production in Comahue.
- More frequent intense precipitation events and flooding in areas where these already occur.
- Continued retreat of glaciers.
- Impact of increased sea level on certain points along the seaboard and coast of the Río de la Plata.

Table 5. Watersheds by System

SYSTEM	Average flow m³/s	%	Outflow Hm³	Drainage basin km²	Specific flow l/sec/km²
Atlantic Watershed					
Río de la Plata(a)	22.031	85,27	694.770	3.092.000	7,1
Buenos Aire Province	147	0,57	4.636	181.203	0,8
Colorado	319	1,24	10.060	92.840	3,4
Patagonia	1.941	7,52	61.211	356.033	5,5
Sub total	24.438	94,6	770.677	3.722.076	
Average	-	-	-	-	6,5
Pacific Watershed					
Various	1.212	4,69	38.222	33.455	36,2
ENDORHEIC					
Independent (b)	42	0,16	1.325	248.871	0,2
Mar Chiquita	114	0,44	3.595	22.030	5,2
Serrano	24	0,09	757	26.555	0,9
La Pampa	6	0,02	189	600	10
Sub total	186	0,71	5.866	298.056	
Average					0,6
Total	25.836	100	814.764	4.053.587	
Average					6,4

(a) Average flow includes 100% of the Uruguay River flow and the surface recorded is the total drainage basin.
Source: Hydric balance for the Argentine Republic. INCYTH-UNESCO, 1994

5.1.2 Consumption of Water to Satisfy Basic Needs

- Water consumption varies considerably in Argentina from 150 to 400 l/inhab/d. On the other hand, it has been calculated that the volume that cannot be accounted for is between 30 to 45% of the water produced. The same happens with micro-measurement, which varies from zero to 100% of the users in a few small localities, although the national average is below 20%.
- The entire population of Argentina is not guaranteed water availability to cover basic needs. The main deficiencies occur in metropolitan areas of larger cities as a consequence of a lack of supply networks and the contamination of surface and groundwater resources. There are also rural populations in arid and semi-arid areas with a jeopardized supply capacity.
- The above occurs regardless of the orderly, pacific and non-conflicting incorporation of the right to water in the Argentinian legal system, and the fact that the right is protected by courts and is accepted and studied by specialized doctrine.

Argentinian positive law in Article 41 of the National Constitution proclaims that all inhabitants enjoy the right to a healthy, balanced environment that is apt for human development and the productive activities needed to satisfy present needs, without threat to the obligation of protecting this right. Although it does not specifically state that the aforementioned is a human right, it is implied in the term "all inhabitants".

Water Supply and Sanitation

FIG. 7 shows the history of water and sanitation coverage in Argentina from 1990-2008. Water services with a connection to a public network grew 11%, while sanitation services by a network remained practically constant, in other words they increased with demographic growth.

According to data form the National Institute for Statistics and Census (INDEC -Instituto Nacional de Estadísticas y Censos) for the first trimester of 2010, the 32 metropolitan areas containing 70% of the national urban population had an average clean water service coverage of 99,6% and sanitary service coverage of 64,5% (BM, 2010). The figures for the Buenos Aires Metropolitan Area (AMBA) were below these averages.

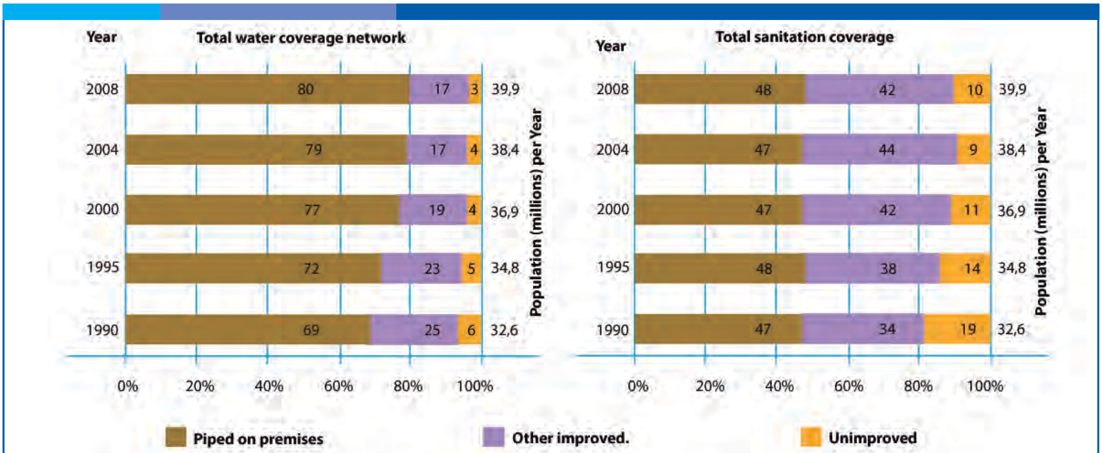
As to wastewater treatment, it is estimated that only close to 12% is processed, one of the lowest percentages in Latin America. In a group of 10 provinces, between 50 and 85% total wastewaters are treated, although in the largest cities treatment is rare (in general, less than 10%).

In recent decades, it is estimated that Latin America and the Caribbean have invested approximately 0.2% of their GIP in water and sanitation. From 1970-1980, Argentina invested an average of 0.17% of its GIP in the area; while from 1981-1991 it fell to 0.08%, although it increased to 0.21% from 1993 to 2001. In subsequent years, investment decreased as a consequence of the macroeconomic crisis and the renegotiation and cancellation of contracts for private operation. Recently though, significant plans for works have been put forth and there have been important investments from the state budget and loans from multilateral banking along with renationalization of most of the greater services, particularly in the AMBA.

5.1.3 Tariff Systems

Regarding financial sustainability of water and sanitation services, international experience shows that income covers the costs of maintenance and operation and a part of capital costs in all countries except those that are less developed. Nevertheless, services are partially subsidized even in more developed countries.

As mentioned beforehand, fee income is insufficient to cover operational and



SOURCE: JMP (2006 Y 2010)

FIG. 7. Use of Drinking-Water Sources and Sanitation Services.

maintenance costs in several services in larger Argentinian cities. In the AMBA for example, where fees have not been modified since 2002, fee income covered 58% of operation costs in 2009, but this figure fell to 47% in 2010. In most of the country however, it is difficult to determine the fee per m^3 because most fee systems are of the "free tap" type in which there is a fixed charge independent of the amount of water consumed.

The estimated value per m^3 of water and sewage services for the services provided by the AySA - Agua y Saneamientos Argentinos S.A (Argentine Water and Sanitation Company) to the AMBA, results from dividing the total income from billing by the number of m^3 water sold, obtaining a figure of US$0.17 per m^3 water consumed.

Many provinces have kept the same fee system since the time when services were operated nationwide by the OSN – Obras Sanitarias de la Nación (National Sanitary Works Company) based on presumed consumption according to surface area, zone, quality and age of the property, differentiating between residential and non-residential users. These variables intend to act as indicators of the water user's income level, solvency and water use, although the fees obtained this way have no statistical correlation with respective consumption. In addition, the fee scheme is based on a complex system and is generally not up to date regarding cross subsidization.

Complementarily, in some services there is an explicitly focused subsidy. In the AMBA it is called a Social Fee Program and has been in practice since 2002. It benefits users in a socially vulnerable situation who are not able to pay the water and sanitation services' fee. Until December of 2009, its beneficiaries were approximately 2% of the registered water users and obtained an average discount of approximately 43% of the value billed.

5.1.4 Droughts and Floods

Due to its geographical location, climate diversity and relief, Argentina is subject to natural events such as droughts and floods. Invariably, they have a direct and significant impact on food production and the economy in general.

Droughts

Droughts occur in many areas in Argentina, in spite of the different characteristics of their climates. They have occurred for extended time periods, even for months and years, and for a variety of reasons, but basically due to water and land use, in addition to climate. Because droughts originate by lack of precipitation for long periods of time, they specifically cause damage to agricultural activities.

Floods

In 1982/83 and 1992 there were severe swellings of the Paraná and Paraguay rivers that also extended to the Uruguay River. The swelling of 1982/83, which lasted more than eighteen months and had a maximum flow of 60,200 m^3/s at the Paraná-Paraguay confluence, flooded an area of more than 30,000 km^2, forcing close to 100,000 people to evacuate and causing damage calculated at over 2,000 million dollars. Consequently, the Secretaría de Recursos Hídricos de la Nación (National Ministry of Hydric Resources) put into action a Hydrological Alert Operation

Center, still in operation, which was originally part of the current INA- Instituto Nacional del Agua (National Water Institute). Unfortunately, the chain of command of the Ministry of Hydric Resources was later down-sized in its rank and competence, in contradiction with the recommendations of the 1997 United Nation's Conference in Mar del Plata.

During the 1992 flood, when the early alert system was already active, there were material damages worth nearly 500 million dollars. It was noticeably greater than the flood of 1966 (43,800 m^3/s) and nevertheless the damages in 1996 were less, because both population and investment in the river valley were lower at that time.

When defining an action strategy against flooding, clearly there is no single response valid under all circumstances and in all regions, and it is impossible to provide absolute protection. There are examples of severe swellings that caused serious damage and were difficult to manage in societies with high technological development such as the one in the Mississippi in 1993 or the Oder in Germany in 1997. These cases show that even first world countries suffer these natural disasters and prove that management of swellings is a current problem to be discussed within the science and technology community.

In conclusion, the importance of investigating water-related natural disasters is strongly linked to the need to define action strategies to avoid them, although it is impossible to find a single answer valid in all circumstances and to ensure complete protection.

Measures to Mitigate Floods

Both structural and non-structural measures are important in the prevention of flood damage, and although to an extent they are different basic notions, they complement each other in mitigating the effects of river swellings. Structural measures such as building physical defenses can be actually added to non-structural measures that lead to a decrease in the cost and risk of floods. In addition, flood disaster mitigation not only depends on activities that can be put into action during the swelling, but must also be the product of combining prevention practices, operational management of swellings and reconstruction and revision after the passing of the flood.

Some actions that can help prevent floods are risk management of swellings; flood contingency plans that establish evacuation routes, critical thresholds for decision-making, and requirements for emergency operations, etc.; construction of structural and non-structural infrastructure for defense against flooding (physical works and alert systems); maintenance of infrastructure for flood defense; territorial planning and management in the entire drainage basin; avoiding inadequate physical and economic settlements in flood plains; and providing information and education to the community in relation to the risks of floods and the actions to be taken in an emergency.

Furthermore, operational management of swellings can be considered complementary to four activities: a) hydrometereological detection of possible swelling formation; b) prediction of runoff conditions; c) alert on swelling severity and timing, and d) emergency response from authorities and the population. In this respect, there is an evident need to develop specific mathematical models and techniques to estimate the variables to be used to alert and warn the population.

Actions to be taken after the flood is over depend on its severity and can include aid for the immediate needs of those affected; reconstruction of damaged buildings, infrastructure and defense works; recovery and regeneration of the environment and economic activity within the flooded area, and revising planning and management actions to be considered in future events.

As stated above, structural and non-structural measures are complementary in mitigating the effects of river swellings. Currently, an environmental view of the problem suggests possible non-structural solutions, such as territorial zoning of flood plains, appropriate control of development and activities in the flood-prone areas, early alert systems and plans for civil defense. The importance of non-structural measures is underlined by the false sense of security in communities living close to works for physical defense as these are designed for a specific critical state, which can naturally by overwhelmed.

Although non-structural measures cover a wide variety of specialized fields, it is vital to mention the importance of early alert systems that are based on the mid-term forecast of potential floods. If an accurate alert is called in a timely manner in quick response basins, deaths can be avoided as no one would be surprised by the event. Ever since an alert system with a telemetry network was installed twenty years ago in the basin of the San Antonio River, in the semi-arid region of the Cordoba mountains, there have been no deaths by alluvial swellings in the touristic town of Villa Carlos Paz. The system functions and gives warning and evacuation signals with only a few hours of anticipation from December to March, not just because this is when intense rainfall occurs, but also because it is the tourist season when campers can be found in risk areas. It is important for plain basin alert systems to produce precise information regularly not only regarding the date of the event and its expected height, but also the time flood levels are expected to remain.

Likewise, alert systems should function continuously as they predict swellings and falls that can affect navigation. Daily hydrometric levels for the cities of Rosario and Santa Fe are estimated twenty days in advance, and then corrected according to the effect of local rains. In every important coastal city, water levels are predicted with a variable amount of time and made public at the proper moment when alert and evacuation levels are reached.

The ways and roads that run parallel to water courses within a great alluvial valley create problems that are very difficult to solve. More than 50% of the bridges that have fallen in the United States for example, have failed because of poor hydraulic design. When roads are built in low slope areas, their embankments can alter the flow of water, changing its direction and causing diversion of the basin. Then, land that was not flood-prone before the building of the road becomes floodable.

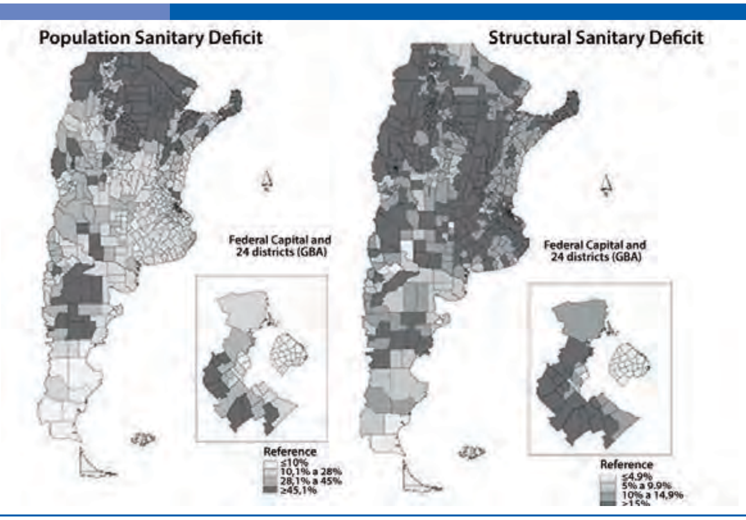
5.1.5 Water and Health

Based on information from the 2001 census, Argentina has developed a sanitary deficit index, which relates access to basic sanitation services and access to the health system. Thus the population not in sanitary deficit, in temporary sanitary deficit (lack of access to the health system) or structural sanitary deficit (no access to basic sanitation services), and finally in critical sanitary deficit (lack both services) can be calculated (Triano, 2006).

According to this study, the average Critical Sanitary Deficit Index for the nation is 28%, with great disparity between provinces (Formosa 53.6%; Greater Buenos Aires 34.8%; Capital Federal 3.4%; Tierra del Fuego 4.5%). Similar behavior is observed when considering the Structural Sanitary Deficit Index which has a national average of 14.5%. These results imply that 42.5% of the population has deficient access to basic sanitary services (no matter if the deficit is critical or temporary) (FIG. 8).

Likewise it should be mentioned that a survey in the La Matanza district found that 66% of those surveyed mentioned having suffered a water-borne disease (Cuenca Hídrica Matanza Riachuelo, 2004).

In addition to problems associated to access to water, Argentina must face the presence of natural water contaminants such as arsenic and fluorine. Prolonged intake of water with high amounts of arsenic can produce certain kinds of skin cancer, cancer of certain internal organs (lung, liver, kidney and bladder), as well as non-cancerous lesions of the skin, such as altered pigmentation and thickening (hyperkeratosis). According to recent studies, the areas exposed to arsenic are home to 2.5 million people (7% of the population) and cover an extension of 435,000 km². According to a document from 2001, the main provinces exposed to levels of arsenic greater than those allowed by the National Food Code (Código Alimentario Nacional), are Salta, Santiago del Estero, Chaco, Tucumán, Santa Fe and La Pampa.



SOURCE: TRIANO, 2006

FIG. 8. Population & Structural Sanitary Deficit.

Regarding diseases transmitted by water, it is worth remembering the cholera outbreak of 1992, which especially affected the poorer population of the provinces of Salta and Jujuy. In some areas in these provinces, water and sanitation services were lacking; in many others the existing services were poorly operated and water was not even disinfected because of supposed budget shortages.

5.1.6 Water and Agriculture

The total potential land apt for irrigation is close to 6,300,000 hectares, of which 2.5 million hectares could be enabled for comprehensive irrigation. Of a total irrigated surface of 1.5 million hectares, 1.1 million (73%) are found in arid and semi-arid areas. 1.75 million hectares have available irrigation infrastructure, while the area under irrigation covers 5% of the nation's agricultural area.

The following points summarize the problems regarding water in the agricultural sector:

- Salinity and poor drainage. Of the total 1.5 million hectares under irrigation, it is estimated that 500,000 hectares are affected by poor drainage and/or excess salinity, to a greater or lesser degree.
- Technically obsolete irrigation systems. Technological backwardness is reflected in poor maintenance methods and obsolete systems for water application and water distribution by gravity.
- Efficiency of water use below 40%.

Although there is strong positive impact on the environment from reuse of treated residual wastewaters in agricultural or forestry irrigation because fewer pollutants go into bodies of water, there is also social and economic impact in the areas where it is applied. Economic advantages lie mainly in that residual water contributes necessary nutrients to crops, which reduces spending on artificial fertilizers and increases agricultural yield apt for human consumption.

The most important experience regarding the use of treated residual water can be found in the province of Mendoza where it is used to irrigate nearly 15,000 has (Campo Espejo, Palmira, Rivadavia, San Martín), in the province of Chubut (Puerto Madrina, Rada Tilly, Comodoro Rivadavia) and in the province of Córdoba (Villa Nueva) where it is used in horticulture, floriculture and forestry.

Irrigation consumes most of the groundwater extracted as a result of evaporation, incorporation into plant tissue and crop transpiration. Unconsumed water recharges aquifers or evaporates. Overall, more than 65% of water extracted is used for irrigation.

A country is considered to be under hydric stress when it uses more than 20% of its renewable water resources. Around the world there are 20 nations in critical condition in this respect as 40% of their renewable water resources are used in agriculture. However, both Latin America and Argentina extract an average of less than 5% of their total renewable water resources for agricultural purposes.

In Argentina, 68% of irrigated surface is found in arid and semi-arid areas while the remaining 32% that belongs to humid regions, is under complementary irrigation.

The most common problems regarding irrigation in Argentina are: salinization due to poor drainage, technological backwardness, poor efficiency and a poor fee system. These causes can be generally related to a lack of awareness on irrigation issues and participatory control of government aid to the sector.

5.1.7 Water and Industry

- Industrial processes use water intensively. For example, in order to produce one ton of plastic, more than 5,000 m^3 of water are required.
- On the other hand, industrial processes produce contaminating wastes that must be treated and controlled. In developing countries 70% of industrial wastes are spilled into water without being treated, as a result the impact on the environment frequently causes greater concern than the amount of water used.
- Pollution in the following areas in Argentina is the consequence of the lack of quality control of contaminating discharge into receiving bodies of water by industrial processes: the Metropolitan Area of the city of Buenos Aires (AMBA –Area Metropolitana de la Ciudad de Buenos Aires), the basins of the rivers Matanza-Riachuelo and Reconquista, and to a lesser degree cities such as Córdoba, Rosario and San Miguel de Tucumán.
- In order to solve the most critical cases – the rivers Matanza-Riachuelo and Reconquista in Buenos Aires and the river Salí Dulce in the provinces of Tucumán and Santiago del Estero- national and provincial governments have strengthened the agencies directly in charge of prevention and remediation of pollution as well as the interjurisdictional basin organizations involved. Both the legal system, at provincial, federal and Supreme Court levels, and national and provincial ombudsmen, are directly supporting these initiatives by increasingly demanding the allocation of sufficient resources to water and environmental management agencies within their jurisdictions and to the interjurisdictional basin organisms that promote coordination and cooperation, and thus demanding results.

5.1.8 Water and Energy: Hydropower

Argentina has a hydroelectric potential estimated at close to 170,000 GWh/year, of which 130,000 GWh/year correspond to inventoried projects in various degrees of development. Of the potential accounted for, 35,000 GWh/year correspond to works that are under construction or have already been built [6].

FIG. 9 shows how each of the seven electricity regions in the country contributes to installed hydroelectric capacity.

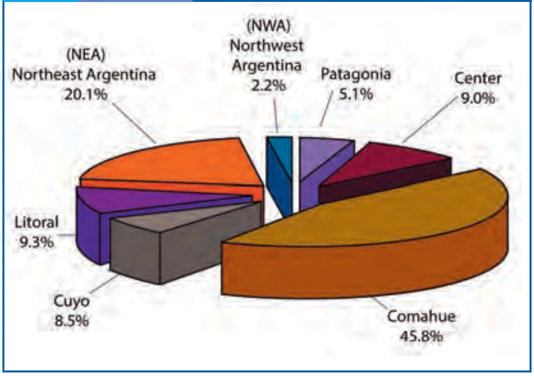


FIG. 9. Installed Hydroelectric Capacity

6 Source: Subsecretaría de Energía Eléctrica

The installed hydropower capacity in a year with average hydraulicity currently covers approximately 35% of the nation's annual electricity demand. If the year were to have a high combined hydraulicity, it could cover 45% of the demand, while in years of very low hydraulicity the percentages falls to 25%.

The largest hydropower station currently in operation is Yacyretá, a bi-national venture shared with Paraguay and located on the Paraná River, 100 km downriver from the city of Posadas. When the project is finally completed, Yacyretá will have a total installed capacity of 3,100 MW, and will be able to generate 19,500 GWh/year.

The joint energy of the projects located in the regions of Comahue, Nordeste and Litoral is equal to over 80% of the annual hydropower supply in Argentina. The basins of the four main energy generating rivers are Paraná, Uruguay, Limay and Neuquén. Attention should be concentrated on these rivers to analyze the influence of their combined hydraulicity on national hydroelectricity.

The projects located on the rivers Limay and Neuquén together concentrate the greatest hydropower potential in the nation with 4,650 MW, or 25% of the peak hour load curve of the Wholesale Electricity Market (MEM – Mercado Eléctrico Mayorista) (19,500 MW, historical maximum recorded in July 2009). In addition, El Chocón, Piedra del Águila and Cerros Colorados are the only seasonal reservoirs in the electricity system, that is the only ones with a capacity to transfer energy from the winter into summer.

The bi-national projects in hand are: Garabí (5470 GWh) and Panambi (5970 GWh) with Brazil on the Uruguay River, and Itatí-Itacorá (11300 GWh) and Corpus Christi (19000 GWh) with Paraguay, on the Paraná River. The main national projects are: Chihuido I on the Neuquén River (478 MW installed capacity), Cóndor Cliff and Barrancosa (1740 MW installed capacity) on the Santa Cruz River, Punta Negra (62.20 MW installed capacity) on the San Juan River, Portezuelo del Viento on the Grande River (90 MW installed capacity) and Los Blancos I and II (443 MW installed capacity) on the Tunuyán River, both in Mendoza.

If these projects were to be built, the nation's capacity for hydropower generation would decisively increase. The relative weight of Argentina's hydroelectricity supply in the future would grow in new basins and would be more evenly distributed along its territory.

5.1.9 Other Uses of Water

We particularly consider the uses linked to navigation and ports, fishing, tourism, etc. Some of their characteristics are presented below.

Navigation and Ports

Inland waterway transport is not nearly used to its potential for bulk transport by trains of barges, although there are great possibilities for growth if coordination with ports of transfer or destination and shipping is improved, if there are better conditions for navigation and an effective sign system. Private initiative has concentrated on establishing ports with very low infrastructure and operation costs on the Paraná River that only require the maintenance of canals in the Río de La Plata. This has proved beneficial for all ports upriver from the port of

La Plata and some natural shallow-water points in the Paraná, with no need for dredging at mooring stations or access canals. However, although progress is being stimulated by a very significant increase in export cargo, mainly agricultural bulk and containers, traffic congestion has also increased on the roads leading to the ports.

On the other hand, a lack of coordination between agencies and deficient control of real estate developments have caused poor exploitation of the recreational and tourist potential of the ports along the Río de la Plata and Paraná River. Two exceptions that illustrate this potential are the ports of Olivos and Tigre, both of which from time to time have combined services for a variety of users in an articulate and harmonious way (sand companies, fruit transportation companies, sporting navigation, amateur fishermen, visitors, the Argentine Naval Prefecture, export of explosives, limited culinary selection). The attraction for tourism and recreation of the port of Mar del Plata has not been followed by other ports along the Argentine Atlantic shore.

Finally, it is worth mentioning that the country should reconsider the possibility of developing deep-water ports along its ocean shore to allow an increase in efficient cargo movement and thus improved competitiveness in exporting goods.

Fishing

The population of hake, the sea fish species of the greatest importance in Argentina, has been calculated to have declined 70% in the past twenty years due to over-fishing. Another group affected by over-fishing within the limits of the continental shelf exclusion zone is the squid. Although prawns are commercially important, their capture is limited and the amounts highly variable.

River fishing is important in the Río de la Plata basin for subsistence, commercial activity in the production of fish flour (shad), recreation and as a tourist attraction (sport fishing of dorado, pacú, tararira, surubí and other gastronomic delicacies). However, capture has not only been affected by the construction of the Yacyretá and Itaipú dams, as the fish ladders do not work adequately, but also by over-fishing and the appearance of exotic species (carp).

Fishing is also a recreational and touristic activity of economic importance in mountain rivers. In these areas, large scale fishing is used to supply restaurants and at certain times, for export. Nevertheless it is important to limit the scale at which it is done to avoid affecting water quality.

Improved control and regulation of fishing activities requires coordination and cooperation between many agencies, and thus must be supported by a long term approach. On one hand it is necessary to make progress in scientific research on the ecosystems involved, including activities that range from the agricultural use of fertilizers, biological agents and agro-chemicals; as well as marine research; investigation of food chains and systematic follow-up of the changes in populations of various species. On the other hand it is also important to provide information on tides, hydrology and meteorology; regulate catches; and study successful management strategies used in other countries.

5.1.10 Preservation of Water Quality

Since the dissolution of the OSN - Obras Sanitarias de la Nación (National Sanitary Works Company), management of water quality and groundwater has suffered great deterioration in Argentina.

Companies that provide clean water monitor their surface and groundwater sources, although their measurements are not sufficient to identify sources of contamination. Unfortunately, lack of information hinders control of contaminating activities, a function formerly performed by Sanitary Works, and to date it has been impossible to achieve a comprehensive approach to this and other obstacles, and as a consequence there has been continuous deterioration of hydric resources, especially in urban, metropolitan and industrial areas. The creation of the ACUMAR -Autoridad de la Cuenca del río Matanza-Riachuelo (Basin Authority for the Matanza-Riachuelo River) arises as a new way to face this issue.

Furthermore, the CIC-Comité Intergubernamental Coordinador de la Cuenca del Plata (Intergovernmental Coordinating Committee for the Río de la Plata Basin) has tried to organize the systematic monitoring of water quality in the Uruguay and Paraná Rivers at the locations where they enter the country. Nevertheless budgetary issues of the national and provincial agencies involved have not allowed the initiative to continue. Because the Uruguay River receives untreated discharge from the food industry, mainly chicken and pork processing facilities, as well as fertilizers and pesticides from crops such as rice and soy bean, and because the Uruguay and Río de la Plata rivers are suffering from algal blooming more frequently, it is necessary for the country to implement a reliable monitoring system.

The recent conflict over the establishment of the Botnia pulp mill company on the east bank of the Uruguay River has attracted attention from the media over its possible impact. Nevertheless, they have not considered that it would also be necessary to monitor other sources of pollution along the Uruguay River that existed beforehand and that also affect water quality.

Environments Affected by Water Quality

The main environmental problem regarding water that can be observed in the many geographical regions of Argentina is the consequence of a lack of discharge treatment (mostly industrial, residential and urban) and a lack of adequate urban planning. An example of this is the settlement in the flood valleys of the Matanza-Riachuelo and Reconquista Rivers, and some of their tributaries.

Untreated wastewater then contaminates the southern coastal strip of the Río de la Plata and part of the Paraná delta. Control is almost non-existent and the factories established in those valleys generally discharge their wastewaters untreated. Additionally, these informal settlements (shantytowns) lack proper water supply and sanitation services, and to make matters worse, dump trash into wastepipes and canals, as they also have no solid waste collection services.

Likewise, the sustainability of surface and groundwater sources faces growing threats due to anthropic modification of land use in drainage basins. Non-conservationist agricultural practices, deforestation, the use of agro-chemicals and changes in land use disturb hydric balance and the quality conditions of water sources.

The following cases stand out in the country:

- Misiones and several areas in the Bermejo basin: increase in the amount of suspended solids due to greater water erosion by deforestation, overgrazing or poor management of arable land.
- Uruguay and Negro Rivers: presence of pesticides and fertilizers in surface watercourses.
- Contamination of shallow reservoirs such as Río Hondo (Santiago del Estero), San Roque and Los Molinos lakes (Córdoba), Lake Lacar (Neuquén) and Lake Nahuel Huapi (Río Negro) because of untreated wastewaters and sewage from urban settlements and riverside industries or those located on the drainage basin.
- Aquifer contamination caused by wastewater discharge into septic tanks, as in "Pueluche" in the Buenos Aires Province or due to intensive and uncontrolled urban and industrial development, as on the shores of the Paraná River, from Rosario to La Plata.
- Contamination of the basins of the Reconquista and Matanza-Riachuelo Rivers in the Buenos Aires metropolitan area. Both basins are extremely polluted and thus directly and indirectly affect the well-being of 5 million inhabitants. It must be mentioned that other important cities like Córdoba, Rosario and San Miguel Tucumán suffer similar, although less serious situations.

The emblematic case of the Matanza-Riachuelo basin presents all types of water and environmental problems: flooding of residential and industrial areas, large sections of a population without sanitary services, jobs for collection and processing of trash that do not follow hygiene, safety and health preservation regulations, and industrial activities that are frequently unreliable.

The formation of the ACUMAR -Autoridad de Cuenca del Río Matanza-Riachuelo (Basin Authority for the Matanza-Riachuelo River) has the main objective of facilitating the activities of various agencies, although a single strategy with an overall view without which it will be impossible to reverse the processes of urban and environmental deterioration, has yet to be reached by consensus.

A second serious water-environmental problem facing Argentina is pollution of groundwater. In most of the country, groundwater management is hardly efficient and therefore there is a lack of quantitative information necessary to assess the current state of water quality in aquifers and the tendencies in each one.

Although the responsibility of groundwater management lies in the provincial governments, these generally do not have sufficient human and financial resources to manage a resource which is much less visible than surface water. Most often, technicians specialized in drilling know groundwater resources better than the authorities, either because studies are expensive, or because there is no information on un-registered wells, most of them in many provinces.

A third water-environmental issue of importance in Argentina is wetland deterioration due to a variety of causes including pollution (Hondo River Dam), construction of drainage systems with poorly organized operation and maintenance (Bajos Submeridionales), illegal canals that alter surface runoff (in the Pampa plains), flow regulation by means of dams that eliminate swellings that previously caused overflows used by subsistence agriculture (Copo, San Gregorio and Figueroa marshlands on the Salado River in Santiago del Estero, Dulce River marshlands) or the natural or man-made blockage of its natural discharge points (Iberá estuary).

Basin Committees provide an ideal environment to rehearse conciliation of objectives when they become open to participation through procedures that circulate initiatives and receive suggestions and proposals from the entire sector affected, before initiating management activities.

5.1.11 Water, International Trade and Globalization: Virtual Water

The concept of virtual water arose in the early 1990's and was defined as water consumed in the making of a product. Water is needed to make goods; therefore the water used to make a product, whether agricultural or industrial in nature, is the product's virtual water. Virtual water is a tool to calculate the real use of water in a country or its "water footprint", and is equivalent to the total sum of domestic consumption and the import of virtual water in the country, minus the export of its "virtual water" to other nations. A country's water footprint is a useful indicator of a country's demand on the earth's water resources.

The 67% of the world's commerce in virtual water is related to the international trade of vegetables, 23% to trade in livestock and meat products, and the remaining 10% to trade of industrial products.

Approximately 57% of Argentina's exports are related to agricultural products, making it one of the main exporting nations of virtual water between 1995 and 1999, with a net export volume of 226.3 109 m^3, only below the United States, Canada and Thailand.

5.1.12 Water and Education

More than 90 % of the population in Argentina lives in large and mid-sized cities. As a consequence, it is necessary for those who train teachers to transmit a founded diagnosis of the following issues: the need for safe water in cities, the treatment and sustainable management of waste and rainwater, the interactions between surface and groundwater with communities, as well as assessing the potential pathways for solutions in specific cases, considering concrete examples that are applicable in the region.

The Ministry of Education and The National Academy for Exact, Physical and Natural Sciences of Argentina have followed the guidelines established in the "Science for all Children" and "La main à la pâte" programs, developed by the Science Academy of the United States and France respectively, and translated the scheme to secondary level students. As one of its first activities, they have intended to introduce the topic of water as fundamental and have involved experts to interact with university professors.

As an example, a positive experience with respect to acquiring water culture at primary and secondary education levels in Argentina and five other countries (Brazil, Denmark, Ghana, Thailand and Japan) can also be mentioned. This occurred with support from the International Lake Environment Committee (ILEC) during the "water decade" established by the United Nations (Martinez, 1993 and 1998).

Regarding education at the undergraduate and graduate levels, a national network for training and management of water resources called Red Argentina de Capacitación y Fortalecimiento de la Gestion Integrada de los Recursos Hídricos -ArgCapNet) (Argentine Network for Training and Strengthening Integrated Management of Hydric Resources) has been made official. It is composed of an important group of government, academic and non-government institutions with the aim to contribute to strengthen abilities for integrated management of water resources in the country, and to provide a framework that is larger and more important than previous proposals in Argentina.
Several initiatives within this framework can be mentioned, such as the Curso Internacional de Posgrado en Gestión Integrada de los Recursos Hídricos -GIRH (International Postgraduate Course for Integrated Management of Water Resources) organized by both the Department of Hydraulics of the School of Engineering at the University of Buenos Aires and the Instituto Argentino de Recursos Hídricos -IARH (Argentinian Institute of Hydric Resources) which began over a decade ago; and the master's degree in Water Management at the Centro de Estudios Transdisciplinarios del Agua -CETA (Center for Transdisciplinary Studies on Water) of the School of Veterinary Sciences at the University of Buenos Aires.

5.1.13 Water Management

In Argentina, water management has developed in a series of steps that have not been the same in every one of its provinces. Nevertheless it is useful to list various concepts that have had an influence on the process:

- Water as a resource the use of which contributes to economic development and labor in the territory.
- Water as a risk factor.
- Water as a resource that links various sectors and jurisdictions in complex ways, and which requires trying new ways of organization.
- Water as a resource which cannot be managed centrally due to a great variety of situations.
- Water as a resource vulnerable to contamination and also as an element the management of which has a fundamental role in the protection of the environment.

Each one of these ideas gave place to innovation in the organization of water management in the following ways:

- The creation of the Dirección Nacional de Irrigación (National Directorate for Irrigation) and then the state-owned company Agua y Energía Eléctrica (Water and Electricity), into which it was absorbed. The state-owned company Obras Sanitarias de la Nación (National Sanitary Works) was also created and became responsible for clean water supply and sanitation in the country's most important cities.
- The establishment of provincial directorates for hydraulics, with the main function of building flood regulation works. Regulatory

frameworks for civil engineering works were perfected (provincial or municipal norms complementary to the Civil Code). The Instituto Ordenador de Vertientes e Ingeniería Forestal (IOVIF) (Institute for Watershed Regulation and Forestry Engineering) was also created, which performed studies and pilot projects on alluvial basins.

- Development agencies to improve coordination between sectors to get major water projects under way (Corporación del Río Dulce [Dulce River Corporation], Instituto para el Desarrollo del Valle Inferior del Río Negro [Institute for the Development of the Lower Negro River Valley], CORFO Río Colorado) were created. Project assessment techniques (incremental analysis of social and economic impact) were divulged during the second half of the XXth century. In addition, interprovincial basin committees were created to promote joint projects (for example, Comisión Técnica Interprovincial del Río Colorado – COTIRC [Technical Interprovincial Commission for the Río Colorado]).
- Hydric Resources Areas were created within national and provincial governments, providing various alternatives regarding their competence and institutional ranks. Interprovincial basin committees were created for interjurisdictional coordination and so were basin agencies to implement interjurisdictional agreements (for example, Comité Interprovincial del Río Colorado – COIRCO [Interprovincial Agency for the Colorado River] and Agencia Interprovincial de Cuencas de los ríos Limay, Neuquén y Negro –AIC [Interprovincial Agency for the Basins of the Rivers Limay, Nuequén and Negro]). During the 1980's, Obras Sanitarias de la Nación (National Sanitary Works) was cancelled and the same occurred with Agua y Energía Eléctrica (Water And Electricity) in the 1990's. Their services were transferred to the provinces and in many cases given in concession to private companies.
- During the last few decades of the XXth century, an "Area for the Environment" was established in the national and provincial governments and assessment techniques for environmental impact were divulged. Environmental issues were included in the reformed National Constitution of 1994 which determined that water management is the competence of provinces. Agencies for hydric resources and the environment proposed the formation of federal councils -Consejo Hídrico Federal (COHIFE) (Federal Hydric Council) and Consejo Federal del Medio Ambiente (COFEMA) (Federal Council for the Environment), to promote coordination between provinces in issues that are not the competence of basin committees or agencies.

The elimination of the state-owned Agua y Energía Eléctrica (Water and Electricity) and Obras Sanitarias de la Nación (National Sanitary Works) transferred the administration of water resources and management of irrigation, clean water and sanitation services to the provincial governments. In most cases, management quality has consequently declined because of inadequate financing and poor technical and management teams.

There have been several causes for the lack of financing for water management. The most important of these was that Agua y

Energía Eléctrica obtained financial resources from electricity production that allowed it to adequately fund essential functions such as studies and projects, hydrometeorologic monitoring, management of regulatory and legal issues, and the coordination between sectors and jurisdiction. Likewise, Obras Sanitarias de la Nación operated in areas where land occupation and socioeconomic level provided an income that was sufficient to cover all of its functions (one of its legal advisory functions was establishing norms on use and extraction of groundwater). An additional cause of deterioration was that although the federation transferred the infrastructure of these two important companies to the provinces, it did not transfer the necessary resources for their operation and maintenance, nor the trained personnel needed for these activities.

Because people in most provinces are not accustomed to improve the management of water by demanding or proposing constructively, the decision-making authorities that assign budgetary resources to the provinces do not receive requests for a greater allocation of financial resources to water management (most popular demands regard issues such as social services, job creation and housing). Consequently, water management in most provinces continues to depend on financial aid from the federation, which implies that the decentralization process has not achieved the objective of providing real independence to provincial decisions. This situation will only be overcome if the Nation increases the co-participation of its provinces in national taxes specifically directed to strengthening water management and if provinces also increase provincial funds for this purpose as a direct response to popular demand.

Two recent developments in the sphere of water management reveal the consensus that has been reached regarding the importance of promoting coordination and participation: the interjurisdictional agreement on Principios Rectores de Política Hídrica (PRPH) (Governing Principles on Water Policies) and Plan Nacional Federal de Recursos Hídricos (PNFRH) (National Federal Plan for Hydric Resources), that promote formulation of provincial and sectoral hydric plans.

Argentina has taken a significant and irreversible step toward water management at the provincial level, because the diversity and extension of centralized management that makes it unviable. However, to complete this process it will be necessary to decidedly move forward in two concrete aspects. One is to include new topics in education regarding practical issues facing water management, thus complementing learning of physical aspects that are already part of the curricula. The other is to include specialized subjects and practical activities to teach fundamental concepts on organization and management in all specialized disciplines that must participate in hydric management.

5.1.14 Summary

In summary, and as a consequence of comparing Argentina with other countries in the region, the nation faces a series of significant challenges to attain integrated management of its hydric resources that would turn into greater well-being for its people and fit in the paradigm of sustainable development.

Overcoming these challenges can be achieved with the development of an agenda of structural and non-structural activities, prior consensus by public and private sectors, which corresponds to a strategic long-term vision on the use of hydric resources, and that translates into increased investment and greater efficacy and efficiency levels in its execution.

5.2 Challenges to the Management of Hydric Resources in Argentina

The overall view presented in this document on the current meaning of water in the world, Latin America and Argentina, enables to appreciate the existence of a clear tendency of water demand growing faster than its supply. Nevertheless, this vision also reveals that water management faces challenges that vary greatly from one nation to the other and from one region to another, as the various factors that influence needs and opportunities can combine in many ways.

Analyses show that the achievement of the main objectives in water management is not clearly related to the provision of water per person in each region or community, or to its income per capita. This implies that the challenges in water management are not only limited to finding new ways to increase availability and reduce demand.

Although the scarcity of water and technical-financial resources that facilitate the increase in water availability, are no doubt extremely important factors, it is relevant to note that the poor efficacy with which resources are assigned is in many cases due to factors that do not depend exclusively on decisions regarding water supply services or the management of infrastructure works.

The worldwide objective of achieving efficient, fair and sustainable use of water is usually interpreted as the same as achieving guaranteed access to basic water supply and sanitation services, in addition to universal protection against flooding and sustainable use of water for the entire population. Currently, some regions show they have reached the first two specific objectives and are taking measures to achieve the third. Nevertheless, the great majority of the regions of the world, including many nations with abundant water resources or those with considerable income, are far from reaching the first two.

Therefore, the main challenges facing water management in many countries refer not only to the basic tendencies that determine supply and demand, in other words the impact of population growth and income on water demand, but also the impact of climate change and the increasing production of effluents and contaminating wastes.

In nearly all countries these basic tendencies are present to a certain extent and it is important to point out that some of them have been able to appease, and at times revert, the tendencies towards growth in water demand per person and in the amount of contaminants spilled into bodies of water. For this purpose they have designed policies that combine structural activities with the application of management tools, including providing information and raising awareness in the population, and involving various sectors in the negotiation of agreements necessary to change the tendencies threatening the sustainability of social and economic organization.

These cases lead the way for other countries; however it is not enough to copy technological or organizational solutions, as it is also essential to promote changes in the attitude of the people through the use of the management tools mentioned above.

5.2.1 Harmful Tendencies

In addition to the tendencies mentioned previously, there are other tendencies that may avoid the attainment of water management objectives if they are not dealt with in a timely manner. Some of these are directly related to failure in water management, but others result from the prevalence of non-sustainable practices in productive activities or land zoning.

The following are some of the negative tendencies regarding the management of water resources:

- Excessive regulation of certain rivers.
- Non-sustainable use of aquifers and a lack of adequate management of groundwater.
- Poor response from those responsible for the management of water and energy towards those in opposition to the building of dams for hydropower production.
- Poor quantification of industrial and urban effluents, the cost of which increases more rapidly than the resources for dealing with them as transgressions rise.
- Water supply for irrigation at a very highly subsidized cost, thus stimulating the inefficient use of water.

The following negative tendencies are not directly related to water management:

- Human settlements in floodable areas.
- Precarious settlements in city outskirts of poor immigrants that cannot pay for water and urban management services.
- Increase in the spilling of non-treated effluents in rivers and lakes.
- The continued and increasing tendency to charge very low fees for water services for reasons other than water management.
- The excessive use of agro-chemicals that contaminate aquifers.
- Rapidly expanding aquaculture that threatens to become an important factor for water contamination if techniques to guarantee its sustainability are not developed.
- Limited progress regarding environmental and economic education for improving awareness about the value of water and the social and environmental cost of poor water management, as well as the need to preserve hydric resources and the environment.

These tendencies are clearly the result of views that ignore that the complexity of water management implies that partial proposals intended to avoid problems in certain fields usually aggravate problems in other fields.

Therefore it is fundamental to create mechanisms that allow decision-making based on the coordination of all sectors involved.

5.2.2 Main Actions to Contain Harmful Tendencies

One of the causes of the harmful and unsustainable tendencies mentioned above is not having been able to integrate the plans of numerous independent agencies and organizations. Integration is necessary to identify the issues they have in common and to search jointly for viable solutions.

The following actions, mainly realized in developed countries but also to some degree in Latin America, have the objective of controlling the processes that already affect the accomplishment of the aims of hydric resource management, or that threaten to do so:

- Improve fee systems and the charging for water services by means of mechanisms that allow subsidies only for vulnerable and needy populations, and encourage the rest to adopt sustainable behaviors.
- Promote the use of techniques that save water in all of its uses and which facilitate its reuse.
- Recover rivers: give them back the part of the flood valley that has been occupied by urban or industrial developments, as far as economically possible, and eliminate sources of contamination.
- Increase awareness among groundwater users on the importance of participative management that can guarantee sustainability
- Expand organic agriculture which is in increasing demand due to its undisputable health benefits. This would imply less contamination of water resources, and therefore its promotion is of interest to water management.
- Study new locations for hydropower projects.
- Eliminate spilling of untreated effluents by means of a combination of programs to aid activities that will deal with both investment and current expenditure for treatment, and awareness campaigns among the population.
- Increase awareness among groundwater users on the importance of participative management that can guarantee sustainability.
- Promote the improvement of technologies that obtain freshwater from sea water, through subsidies for the activities that use them in a limited time span.

The most important actions in Argentina are:

- Execution of expansion and improvement works to guarantee universal access to water and sanitation services.
- Fee scheme: agreement on fee levels and improved fee collection.
- Promotion of plans for urban recovery in all cities, respecting criteria that ensure their consistency.
- The necessary awareness to install systems for groundwater management in all provinces.
- Awareness campaigns to sustain firmer action from agencies that supervise observance of norms forbidding contamination of rivers, lakes, aquifers and shores.
- Construction of new hydroelectric ventures.
- Promotion of awareness among farmers on the sustainable use of agro-chemicals.
- Promotion of organic agriculture.

5.2.3 Aspects in which Coordination and Cooperation among Sectors is Essential

Experience on water management accumulated throughout centuries has proved that cooperation among sectors and jurisdictions is a necessary condition to accomplish the objectives of integrated water management.

In this context, it is essential to reach agreements regarding two key aspects:

- A consensus with respect to the basic needs of the people.
- Coordinated action between urban, water and environmental management.

One of the main objectives of the integrated management of hydric resources should be to coordinate the management of sectors with influence on decisions regarding the establishment of persons and businesses.

Policies used by certain countries to avoid migration flows that tend to destabilize the finances of both cities of origin as well as cities of destination, have generally relied on giving aid to the former to increase their attractiveness as places to live and do business by providing better services and opportunities for productive activities. As with any aid mechanism, this policy has not been easily implemented, although it has been successful in some countries.

The most noticeable case has been the generous aid provided by the former West Germany to the former East Germany which helped avoid migration on a grand scale that would have caused enormous economic and social costs in both regions.

This is a useful example of the implications of the concept of integrated management: it not only includes intersectoral coordination but also interjurisdictional coordination on a national scale between sectors indirectly related to water.

Thus an essential objective of water management is to promote an atmosphere of collaboration between the various sectoral and jurisdictional actors allowing consensus to be reached and providing a rational base to combine aid mechanisms for people, sectors, or jurisdictions, while maintaining economic incentives that promote healthy competition in as many spheres as possible.

5.2.4 The Role or Coordination and Cooperation Between Fields

The considerations mentioned above imply the additional need to bring together tools from a variety of fields such as engineering, economics, sociology, urban planning, law and management within a common vision. This global viewpoint would on the one hand make clear that agreements fixing minimum standards for water and sanitation services, as well as flood prevention must consider the limitations imposed by economics and technology, and on the other allow to agree on goals and thresholds to be considered as data for economic analysis performed by public and private agencies and for urban planning.

A fundamental objective of hydric management is to promote a climate of cooperation that is essential to reach agreements between sectors, jurisdictions and actors, regarding not only the goals and thresholds mentioned but also in search of the least expensive solutions to accomplish them. Cost-effectiveness is important because achieving management that coordinates the various uses of water for the purpose of maximizing reuse and reducing purification and treatment costs in each water basin is generally a necessary complement to market mechanisms. To promote cooperation among agencies, and also between agencies and individuals, all relevant information needed to understand the challenges faced by management must be made public. Awareness campaigns are also important before taking governmental measures, so the population understands what these measures are for and has the possibility to express their opinions and interests in a timely manner.

Sufficient human and financial resources are another requisite for the fulfillment of hydric management responsibilities. This can only be accomplished if the people know the problems confronted by management and have information on how these can be solved, as the corresponding taxes and contributions will only be sustainable if their purpose is understood and justified properly. Indeed, it is fundamental to remind the population continuously that payment for water management services has two functions: to stimulate efficient use of water and infrastructure and also to cover at least part of the costs for providing these services.

It is generally accepted that sanitation must be guaranteed by governments and that all people have the right to a minimum supply of clean water, no matter if they are able to pay for it. Nevertheless, the search for the least expensive ways to reach such goals through cooperation agreements must be balanced with additional agreements that promote rational use of water in all sectors.

5.3 Proposals for the Development of Hydric Resources in two Priority Areas: Water and Sanitation, and Water and Energy

To complete this work with concrete proposals, and according to the information, viewpoint and experience of the authors, two priority areas have been selected as having the greatest prospects regarding technical and political viability, social and environmental urgency and economic feasibility after considering their general repercussions and foreseeable externalities. These areas are "water supply and sanitation" and "hydroelectricity supply". The challenges and proposals for the development of hydric resources in both areas are presented below.

5.3.1 Water and Sanitation

The main challenge faced by the nation in the area of clean water and sanitation is universal supply.

There is an urgent need to supply the millions of inhabitants that lack clean water and sanitary sewage. Likewise, it is indispensible to execute works that allow treatment of wastewaters and to create awareness among government officials, professionals, technicians, operators and the population at large on the rational use of water and the protection of its quality.

Among others, this creates the following challenges:

a. To design and execute socially and economically sustainable investment plans that establish universal services as a priority and guarantee financing in the appropriate cases by assigning necessary funds within the budgets of public organizations.

According to information from studies on the investment required to provide universal access to services in Argentina (IBD, 2005, 2007), an estimated 10,000 million dollars would be needed if "access to safe drinking water", "improved sanitation" and wastewater treatment were included under this term. This estimate is a minimum, considering the quality of the services contemplated. If the goal was to universalize both services including network connections in urban areas and a greater degree of effluent treatment, this amount would at least double.

The many social benefits (externalities) associated to universal access to adequate clean water and sanitation services justify such an investment. These benefits include improved health and its impact on education and jobs; reduction in expenses for alternative solutions, including the cost of bottled water; and improved environmental conditions, all of which directly affect quality of life.

A WHO report has calculated that the cost-benefit ratio of investment in water and sanitation systems in a group of countries including Argentina would be approximately 15. This means that for every currency unit invested, there would be 15 times the benefit. Likewise, if total coverage for both services including connection to a public network is contemplated, then the cost-benefit ratio would be 5. Both of these scenarios lead to positive socio-economic benefits.

The differences between them basically result from the much greater cost of expanding water and sanitation networks than to invest in "improved services", while the benefits obtained by each solution are not equally proportional to the respective costs. In this regards, installing service of lower quality in countries or areas with less economic resources would allow to shorten the required time to achieve universal access to safe water and improved sanitation.

b. To improve economic sustainability of the service and greater rationality in fee schemes.

At present, tariff income for services in many major Argentinian cities is insufficient to cover operation and maintenance (O&M) costs.

The rationale behind the fee scheme is given by its capacity to financially sustain the service, which in turn depends on the extent to which fee value reflects its cost. The use of micro-measurement as a base to billing according to consumed volume, contributes to economic sustainability because it promotes a reduction in non-essential consumption.

Chile, Colombia and some of the most important operating services in Brazil (the state of Sao Pablo, among others) have developed lengthy and systematic processes to fix fees based on costs and they have led to a significant real-term increase in income for the service providers. In addition, these regions have implemented the generalized micro-measurement of consumption. The cost of water and sanitation services in Santiago (Chile) and Sao Pablo (Brazil) is close to US$1 per m^3, in Bogotá (Colombia) it is close to US$1.5; while in contrast, in the metropolitan area of Buenos Aires the average cost is only US$ 0.17per m^3.

While micro-measurement in these countries is practiced nearly in their entirety, it is estimated that only 20% of the billed volume in major urban areas in Argentina is the result of micro-measurement of consumed water. One of the main conditions for the success of this practice is that fee values are fixed at a level that allows the recovery of O&M costs and at least some of the investment costs, especially those associated to maintenance and restoration of infrastructure.

Nevertheless, subsidy systems must be implemented to aid poorer or more vulnerable households that do not have the conditions to pay fees that cover costs.[7]

It is worth noting that in many countries, no matter the state of their economies, investment in basic water and sanitation works is to a great extent covered by their governments, and there are no expectations to recover investment through fees, as a result of the extremely important social and environmental impact of these services. As mentioned previously, in countries or regions with poor socio-economic development, it is advisable to first provisionally reduce the quality standard of the services to be able to attain sooner the much needed universal coverage.

c. To increase efficacy levels of operator management and coordination between sectors and jurisdictions.

Sustainability of water services by means of fee income demands improved management efficiency and the resulting minimization of costs.

An area of special interest in cost reduction and improved efficiency in the sector is minimizing physical losses, in other words, reducing the amount of water that is not accounted for. In main urban areas, losses from water systems are in the range of 40 to 45% of the volume of water produced. To reduce such losses would produce significant benefits as a result of lower operation costs and less investment in installed capacity in plants, networks and other facilities.

It is worth noting that in calculating benefits, only the direct impact of cost reduction regarding operation and investment (greater installed capacity available in plants, networks and other facilities) is considered, while required investments and incremental O&M expenses are accounted for as costs.
Regarding this issue, the generalization of micro-measurement would help detect network losses more precisely and contribute to more efficient management by service operators.
Finally, there is a need for a specific and independent legal and institutional framework

7 In the context of a critical evaluation of how urban water supply services are privatized according to "Washington's favorite solution", Sachs, J. (2008) suggests: "An efficient agreement between public management and privatization can be achieved by demanding that private suppliers offer a minimum vital fee that guarantees all families a fixed amount of water daily free of charge for vital necessities (drinking, cooking and hygiene). The amount consumed beyond this minimum would be charged at market values per cubic meter. In this way, even the poorest people would have a minimum guaranteed amount of water."… "Depending on the exact structure of the public-private enterprise and the norms regulating prices, money from the public sector budget could be used to reimburse the water supplier for the free minimum water supply." (pp. 185 and 186).

as well as technical and financial regulation for fees to reflect efficient costs.

d. To perfect the information system regarding management and results.

Making fee schemes reflect costs and making them cost-efficient is related to the quality of the corresponding accounting and technical information. Some Latin American countries have made important efforts in this regard, such as systems for regulatory accounting in Chile, Colombia and Peru, as well as the AMBA services in Argentina.

At a regional level, efforts have been made in the past few years to organize a system of indicators for comparative analysis (benchmarking) through the Asociación de Entes Reguladores de Agua y Saneamiento de las Américas (ADERASA) (Association of Regulatory Entities for Water and Sanitation in the Americas).

e. To promote participation of civil society and local authorities.

Participation of civil society and local authorities is an essential mechanism to ensure that water and sanitation services are provided with the required quality, that universal coverage is achieved as soon as possible, and that fees are fair and reasonable. Civil society can participate through non-governmental organizations or by taking part in public opinion consultations regarding investment plans and other relevant aspects of the service, in public hearings or in the user committees organized by regulatory entities. There are also cases in which the community participates directly in decisions to expand services, mainly in suburban and rural areas. Likewise, it is important to mention the organization of operating entities in the form of user's cooperatives, which is very common in Argentina, especially in small and mid-sized localities[8].

Suggested actions to overcome the challenges considered:

- Promote and prioritize investment in the sector in light of the resulting benefits of its impact on public health, the environment, the economy in general, poverty reduction and social cohesion.
- Establish explicit incentive mechanisms for efficient management of operation companies and the rational use of services. Fee schemes should include incentives to rationalize water consumption and supply, by means of a significant increase in micro-measurement of the volumes consumed by users for example, as well as investment to reduce losses in the water networks.
- Fix fee levels so they cover the costs of O and M and at least part of capital amortization, apart from considering subsidies for users without the capacity to pay.
- Strengthen regulation and control of services and guarantee that the agencies responsible for these functions are technically capable and can act independently.

8 There are close to 750 user´s cooperatives that provide clean water services in Argentina and they represent approximately 17% of the population with water service from a network in the country.

- Improve legal and institutional mechanisms for the participation of society and local authorities. This includes better diffusion and communication regarding the performance of operators and control authorities, as well as increasing educational activities on the issues of clean water and sanitation and the importance of preserving public health and the environment, especially in primary and secondary schools.

5.3.2 Water and Energy

The nation faces the challenge of increasing hydropower participation within the conventional supply to generate extensive amounts of electricity (Hydro + Thermal + Nuclear power). This creates the following challenges, among others:

a. To promote the development of hydropower works in regions of the country where not only the characteristics necessary to generate hydropower exist, but where there would also be additional benefits associated to the control of swellings, regulation of flow and the addition of reservoirs. It was previously mentioned that Argentina has a hydropower potential of 130,000 GWh/year in projects inventoried in various stages of development. However only 35,000 GWh/year correspond to works currently in operation. The country would not only benefit from the clean energy generated, but also from the control of flows and floods, especially in Andean and Patagonian regions where water is scarce.

b. To promote hydropower works that allow a more balanced energy supply with an average joint hydraulicity of close to 40% of demand. Current electricity demand in Argentina is close to de 115,000 GWh/year. The part corresponding to hydropower in a year of average joint hydraulicity is 35%.

Assuming a 4% annual growth in demand and in order to supply 40% of the demand with hydroelectricity (as advised by energy specialists) and thus achieve a more balanced energy supply, an additional 43,000 GWh/year must be added by other projects along rivers that are not shared with other countries such as Cóndor Cliff, La Barrancosa, Paraná Medio, and El Chihuido 1, plus 5,000 GWh/year from an increase to full capacity (83 meter level) of the Yacyretá.

Table 6 shows the anticipated installed capacity and the estimated building costs of reservoirs on non-shared rivers.

Suggested actions to overcome the challenge considered:

- To carry out the relevant studies and projects to complete the design of the main reservoirs and energy-generating works in both national rivers and those shared with other countries.

Many of these tasks imply updating original ideas proposed several decades ago regarding today's technical design and multipurpose reservoir operation for the generation of hydropower. In particular, there is a need for complete and updated studies to assess environmental impact of the work on a local and basin scale.

- To bring these studies together with project assessment that considers not only benefits but also direct and indirect impact or externalities on socioeconomic activities and the environment.

Table 6. Installed Capacity and the Estimated Building Costs of Reservoirs on Non-Shared Rivers.

River	Province	Reservoir	Expected installed potential (MW)	Investment (millions of US$)	US$/kw
Neuquén	Neuquén	Chihuido I	637	1.500	2.35
Santa Cruz	Santa Cruz	Cóndor Cliff and Barrancosa	1.740	4.000	2.30
San Juan	San Juan	Punta Negra	62	380	6.13
Grande	Mendoza	Portezuelo del Viento	90	265	2.94
Tunuyán	Mendoza	Los Blancos I and II	480	1.000	2.08
Sources: Ing. Luis Bergman (EBISA); Ing. Juan Lucchilo (CAMMESA)					

These elements are necessary to promote management linked to the viability of the investment required to develop projects and determine their priority with participation and approval from the social actors involved.

- To analyze electricity fees in comparison to international data to make power generation viable and thus determine how much of the investment needed can come from fee collection.

A general assessment of the energy market in our country makes it clear that fee levels for energy are close to 20% below the international average. Major energy consumers, representing less than 5% of the demand, pay greater fees, although they do not go beyond international prices. Table 7 and FIG. 10. compare fees for electricity (in particular thermal energy companies) in several Latin American countries. Hydropower is an underestimated resource in our country and there is a need to promote the development of works to increase diversity of supply. This would bring long-term benefits such as a reduced impact of greater prices for oil and oil derivatives, energy production with low environmental impact and no greenhouse gas emissions, regional development related to water supply and water availability for irrigation, and the possible development of sporting and tourism activities.

Based on these criteria, it seems reasonable to orient public investment to build works accordingly. Aligning fees with international standards will allow more interest from private investment both in the construction and operation of new venues.

- To work with Brazil and Paraguay in the planning, building and usufruct of the energy produced by the Garabí dam on the Uruguay River, and Corpus Christi on the Paraguay River, for the purpose of guaranteeing their development and to benefit each of the parties.

Garabi dam. This project on the Alto Uruguay promoted by EBISA & ELECTROBRAS, considers the building of two dams, Garabi and Panambi, with 1,152 and 1,048 MW

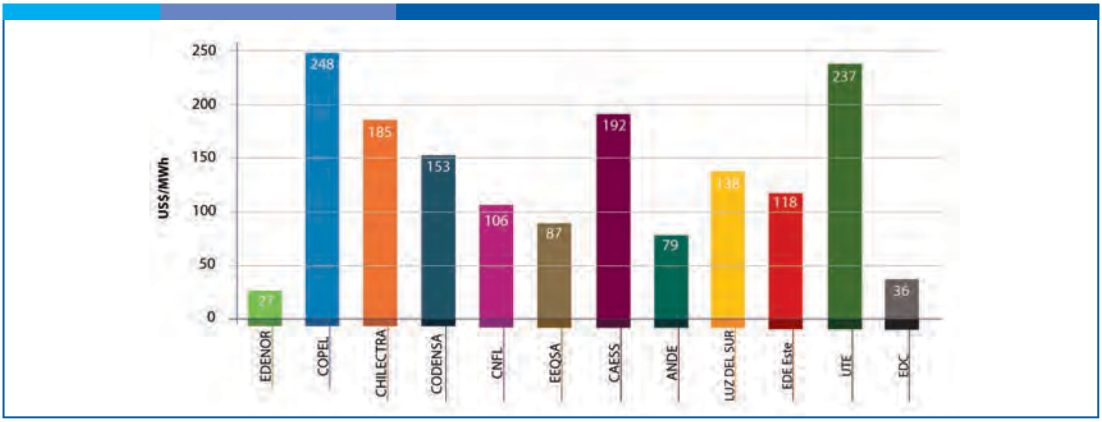


FIG. 10. Electricity Costs for Residential Customer Rd. Minimum Electric Power – 200kWh/month – BT. March/2010.

Table 7. Main Features of Electricity Suppliers and the Concession Areas

Electricity Suppliers	Country	Customers (December 2009)	Density (Customers/Km²) (December 2009)	Concession Area
EDENOR	Argentina	2,626,000	566	Greater Buenos Aires- Federal Capital
COPEL	Brazil	4,030,000	21	Panamá
CHILECTRA	Chile	1,579,000	746	Santiago
CODENSA	Colombia	2,364,000	168	Bogotá
CNFL	Costa Rica	487,000	540	San José
EEQSA	Ecuador	809,000	55	Quito
CAESS	El Salvador	521,000	114	San Salvador - Central
ANDE	Paraguay	1,159,000	3	The Whole Country
LUS DEL SUR	Perú	833,000	301	Lima Metropolitana- Southern Zone
EDE Este	Dominican Rep.	348,000	30	Santo Domingo- East Zone
UTE	Uruguay	1,283,000	7	The Whole Country
EDC	Venezuela	1,154,000	223	Caracas- Central District
Main Energy Customers by Sector				
	Customers	**Electric Power**	**Consumption**	**Voltage**
Residential	Rd	Minimum Supported	200 kWh/month	BT
	Re	Minimum Supported	400 kWh/month	BT
Commercial	Cd	10 kW	1.000 kWh/month	BT
	Cef	10 kW	2.000 kWh/month	BT
Industrial	Ie	100 kW	25.000 kWh/month	MT
	If	300 kW	50.0000 kWh/month	MT

respectively and a joint average annual energy of close to 11,440 GWh. It is important to quicken the studies on the technical, economic and geologic viability of these two potential dams.

Corpus Christi. This hydroelectric dam is planned to be built on the upper course of the Parana River, close to the town of Corpus in the Argentinian province of Misiones and Puerto Bella Vista in Paraguay, some 50 kilometers northeast of the cities of Posadas in Argentina and Encarnación in Paraguay. It will have an elevation of 105 masl and work coordinately with the existing Yacyretá (Argentina-Paraguay) and Itaipú (Brasil-Paraguay) projects and with the Itacorá-Itatí (Argentina-Paraguay) dam currently under construction.

At present, the possible project in Pindo-í is under consideration. It is proposed to have 140 MW Kaplan turbines, a planned installed capacity of 2,880 MW; it would produce an average annual amount of 20,175 GWH, and would affect 13,966 has. of land.

Additional Comments

The construction of hydropower projects of medium to large capacity has been many times proved to be highly unlikely without the predominant participation of national or provincial governments, especially in a country under the conception and economic structure of Argentina. Taking this into consideration, what potential impact would convince the State to promote hydroelectric projects?

a. The increase the reliability of electricity supply by diversifying its sources.

b. The reduction of greenhouse gas emission of the installed generating capacity.

c. The reduction of the impact of a potential increase in oil and its products in the future.

d. The opportunity to give hydropower works other uses that are as important as electricity generation, although less profitable (controlling swellings, irrigation, tourism, navigation, etc.).

e. The development of a region for the purpose of balancing it with others and thus avoid migration for geopolitical reasons.

In conclusion, it is not the potentially high fees which take so long to recover what may generate this type of intensive investment of capital in the future, but rather government decisions which result from political power and the conviction of the importance of development.

6. Interjurisdictional and International Hydric Resources (Appendix I)

The National Constitution states that the original command over rivers belongs to provinces (Art. 124) while the Civil Code establishes that water is a good of public domain (Section 2340, subsection 1). However, these legislative bodies do no typify the relationship established between provinces bathed by the same waters. Consequently, when a basin spans over the territory of several provinces or of a province and the city of Buenos Aires, each jurisdiction could adopt decisions that could harm the others or miss the opportunity to manage the basin rationally and fairly without being outside the law.

The most adequate way to accomplish coordinated management of water is within a basin viewpoint. Agreements are usually the most adequate way to coordinate water management, although in some cases participation of the national authority has been proposed and put into practice.

The reform to the constitution of 1949 authorized the National Congress to legislate (Art. 68, paragraph 14) and the Executive power to execute the policy on interprovincial rivers (Art. 83, paragraph 2) and to nationalize waterfalls (Art. 40), although it was revoked by a Constituent Convention in 1957. Law 13030 conferred regulatory faculties on interprovincial rivers to a national agency to guarantee rational and harmonious use along their entire course, although it is not applied.

In 1948, Tucumán and Salta celebrated a treaty for the construction of a dike on the Tala River and to share its water equally (National Law 956, decreed August 7, 1948; sanctioned June 30, 1948).

In 1956 the Comisión Técnica Interprovincial Permanente del Río Colorado, COTIRC (Permanent Interprovincial Technical Committee of the Colorado River (Tratado de Santa Rosa, August 30, 1956), formed by the Basin Provinces (Buenos Aires, Mendoza, La Pampa, Neuquén and Río Negro) promoted an interprovincial agreement on the use of river waters that was subscribed in the Sexta Conferencia de Gobernadores del Río Colorado (Sixth Conference for the Colorado River) on October 26, 1976, formally defined in February 1977 and ratified by National Law 21611 January 8, 1977 and Laws 8663 of the Province of Buenos Aires, 750 of the Province of La Pampa, 4116 of the Province of Mendoza, 964 of the Province of Neuquén and 1191 of the Province of Río Negro. The agreement was based on numerous studies that culminated in a definitive study by the United States' Massachusetts Institute of Technology. Its results were considered an adequate base for an agreement by the technical and political standards of the five provinces of the basin.

In 1983 the Comité Interjurisdiccional del Río Colorado (Interjurisdictional Committee for the Colorado River) was formed to oversee the observance of the agreement, funded by the provinces and the national government (Law 22721).

An agreement celebrated by the National State with the Northwestern Provinces created the Hydric Basin Committees for the basins in the region (San Salvador de Jujuy, January 18, 1971, and ratified by national decree 4361/71). This originated the Basin Committees of the rivers Salí Dulce and Pasaje Juramento Salado. The Hydric Basin Committee for the Bermejo River was also created by decree (Resistencia, April 14, 1972) and another was created on similar bases for the basin of the Gran Rosario. Another agreement between the national government and the governments of Córdoba and San Luis created the Basin Committee of the Quinto-Conlara Basin (September 19, 1979). Some of these basins are sub-basins of the Paraná Basin, which is in turn a tributary of the Río de La Plata.

The committees' mission was simply to formulate recommendations, supervise the collection and analysis of data regarding water and to promote studies and research to assess the use of hydric resources in each basin. They were intra-federal, decentralized, multi-jurisdictional and singular agencies with capacity in public law because they originated within interprovincial agreements and acts of the National Government.

The Basin Committee for the Salí Dulce River became the Comité Intrejurisdiccional de la Cuenca del Río Salí Dulce (Interjurisdictional Committee of the Basin of the Salí Dulce River) in January 2007, with the signing of an interjurisdictional treaty between the five basin provinces and the Nation. Its aim is to promote the drawing of a Management Plan for the basin with consensus between all parties, to be executed by the strengthening of provincial agencies for water and the environment.

The basin committees for the rivers Juramento-Salado and the northwestern region of the La Pampa plains, which receives extraordinary contributions from the Quinto River, are near the signing of interjurisdictional treaties similar to the one for the Salí Dulce River.

The following were also created with participation of the National Government:

a. Comité Intergubernamental Coordinador de la Cuenca del Plata (Intergovernmental Coordinating Committee of the Plata Basin), to coordinate the activities of the provinces in the basin, between provinces, with the National Government and between the National Government and foreign states that share the basin (Law 23027).

b. The Executive Entity Presa Embalse Casa de Piedra (National Government, La Pampa, Río Negro, Buenos Aires), who built and manages the Casa de Piedra Reservoir.

c. Comisión Regional del Río Bermejo (COREBE) (Regional Commission for the Bermejo River), a regional development corporation, to carry on studies and projects regarding the Bermejo River. It includes the National State and the provinces of Chaco, Formosa, Jujuy, Salta, which are found in the basin, and the provinces of Santa Fe and Santiago del Estero who expect to benefit from its management (Convenio de Buenos Aires [Buenos Aires Agreement], 10/2/81 ratified by national law 22697).

d. Autoridad Interjurisdiccional de las Cuencas de los Ríos Limay, Neuquén y Negro (Interjurisfictional Authority for the Basins of the Rivers Limay, Neuquén and Negro) created by the interjurisdictional agreement signed in Neuquén on December 16, 1985 by the National State and the provinces of Neuquén, Río Negro and Buenos Aires (ratified by National Law 23896). It receives resources from hydropower generation and performs hydrometeorologic and coordination tasks. In spite of its name, it does not have functions expressly delegated from provincial agencies with competence in hydric management.

e. Autoridad de la Cuenca Matanza-Riachuelo (ACUMAR) (Authority for the Matanza-Riachuelo Basin), an interjurisdictional public-law institution formed by the National State, the province of Buenos Aires and the Ciudad Autónoma de Buenos Aires (Independent City of Buenos Aires) (Law 26168, Art. 1). Its functions include regulation, control and promotion of industrial activities; unification of disposal schemes for wastewater in bodies of water and gas emissions; provision of public services, other environmental activities, prevention, sanitation, restructuring and rational use of natural resources; planning for environmental management of the basin and the execution of the Plan Integral de Control de la Contaminación y Recomposición Ambiental (Comprehensive Plan for the Control of Environmental Restructuring and Pollution).

Because Argentina is found on the lower section of the Río de la Plata Basin, it has always had a special interest in the development and exploitation of the basin within international agreements. Whenever a basin spans several nations, one nation might adopt decisions that could harm another or the opportunity to manage the basin comprehensively and fairly might be missed.

To achieve comprehensive and fair water management, it is best to focus it on each individual basin, which requires the intention of the nations involved. For this reason, within the VII International Conference of American States, the Montevideo Statement on the use and exploitation of international basins in the American continent, which is a principle for international law and has been followed by further statements along the same lines, was issued (1933). It has promoted the formation of a regional system for the Plata basin which approved principles applicable to international basins and some particular recommendations for specific works. Within the Asunción Conference of Ministers of Foreign Affairs and from the many negotiations within the framework of the Plata Basin system arose Resolution No. 25 on June 3, 1971 which:

a. Subordinates the use of contiguous rivers to previous agreements between riparian countries.

b. Allows each nation to use successive sections of the rivers they share[9] according to their needs, but without causing considerable damage to the other States.

In the United Nations Conference on the Human Environment (Stockholm, 1972), Argentina achieved recognition of the obligation to notify well in advance of "important activities regarding water that may have a significant effect on another country" (Recommendation 51). In the UN Conference on Environment and Development (Río de Janeiro, 1992) Argentina attained the recommendation to avoid causing harm to the environment of other nations and regions beyond the limits of national jurisdiction (Principle 2), and also to provide prior and timely information to potentially affected States on activities that may have significant adverse transboundary effect and to consult with those States at an early stage and in good faith (Principle 19). The UN Conference on Sustainable Development (Johannesburg, 2002) committed the signatories to increase access to basic needs such as clean water.

In the bi-national scope, Argentina and Uruguay have accomplished true models of international practice. To build and operate the works at Salto Grande, they reached

9 In the resolution quoted, "international rivers of successive course" refers to rivers that run from one country to another, such as the Paraguay and Uruguay Rivers when they run from Brazil to Argentina; while rivers that separate countries are called contiguous rivers.

agreements (Treaties signed 12/30/46, 11/26/58 and 10/20/72), provided timely information on the projects to Brazil and accepted its observations to avoid the edge of the reservoir from harming its environment (Joint Argentinian- Brazilian –Uruguayan Statement of Buenos Aires, September 23, 1960). They reached agreements again for the Plata and Uruguay Rivers (Treaties signed on 11/19/73 and 2/26/75, Laws 20645 and 21413) that regulate the use and preservation of these rivers. The environmentally respectful behavior always shown by both countries could not avoid the controversy brought up by Argentina against Uruguay due to the installation of pulp mill plants; this was settled by the International Court of Justice at The Hague in 2010.

With Brazil and Paraguay, Argentina agreed to harmonize the Brazilian-Paraguayan reservoir of Itaipú with the Argentinian-Paraguayan reservoir project of Corpus (Acuerdo Tripartito de Puerto Presidente Stroessner [Tripartite Agreement of Port President Stroessner], October 19, 1979). With Brazil it agreed on the joint use of the bordering stretch of the Urugauy and Pepirí-Guazú rivers, and the use by each State of the unshared stretches according to each nation's interests and without causing relevant harm to the other, according to the consideration and description made by both parties involved (Treaty of Buenos Aires, May 17, 1980; ratified by Law 22740).

With Paraguay and Bolivia, Argentina created the Comisión Trinacional para el Desarrollo de la Cuenca del Río Pilcomayo (Trinational Commission for the Pilcomayo River Basin), for the study and execution of joint projects on the river (La Paz, Bolivia, February 9,1995; approved by Law 24677). This commission received important financial support from the European Union, allowing it to engage the formulation of a Master Plan for the development of the basin. At present, this plan is being executed at the pace allowed by the collection of funds from various sources.

Bolivia and Argentina created the Comisión Binacional para el Desarrollo de la Alta Cuenca del Río Bermejo y el Río Grande de Tarija (COBINABE) (Binational Commission for the Development of the Basin of the Bermejo River and Río Grande de Tarija), to perform studies, research, projects and works, as well as exercise certain authority and police functions (Tratado de San Ramón de la Nueva Orán, June 9, 1995, approved by Law 24639).

By means of the Acta de Santiago (Act of Santiago), June 26, 1971, both Chile and Argentina agreed not to put into effect unilateral activities that could cause harm to the other's environment and to begin joint actions for environmental protection, preservation, conservation, and clean-up.

7. Legal- Administrative Framework for Water in the Argentine Republic (Appendix II)

The National Constitution sets the base for all Argentinian law, distributes authority between the Nation and its provinces and forces both to respect certain government principles such as the separation of powers, the establishment of the municipal system and to yield to the minimum environmental budgets imposed by the National Congress and the international treaties it approves.

The Constitution bestows the Nation competence over water matters when it gives the National Congress power to legislate on topics such as navigation by declaring it free for all flags (Art. 26,b), international and interprovincial trade (Art. 75, Sec. 13), substantive codes (Art. 75, Sec. 12), and minimum budgets for environmental protection (Art. 14).

The Constitution also gives the Congress competence to approve international treaties celebrated by the Executive Power (Art. 75, Sec. 22) which must be observed by the provinces and promote the construction of navigable channels and the exploration of inner rivers. The Nation cannot regulate matters that the National Constitution did not delegate to the Congress (Art. 121). Likewise, the National Constitution authorizes the provinces to perform actions regarding:

a. Creation of regions, for economic and social development and the establishment of agencies with faculties to accomplish their objectives (Art. 125). Basins are includes as one of these regions.

b. Celebration of partial treaties with other provinces to administer justice, economic interests, and activities for common good, with knowledge from Congress (Art. 125) and to regulate management of interprovincial basins.

c. Regulation of management and use of water under their jurisdiction. It gives provinces original domain of natural resources (Art. 124). The Civil Code awards provinces public domain over most waters (Art. 2340) and the power to enforce law in the rest (waters which begin and end in the same premises).

d. Sanction of the necessary norms to legally protect the environment, use natural resources rationally, preserve natural and cultural wealth in addition to environmental education, and finally complement the minimum budgets for environmental protection determined by the Nation, as entrusted by the 1994 reform not only to the national State but to the provinces as well (Art. 41).

Although the National Constitution did not specifically entrust the National Congress to sanction norms regarding water, the functions attributed to it in the Civil Code allow it to establish uniform principles on water matters. The National Civil Code determines that practically all water is of public domain, at least all that is of community interest, including rivers, their flows, other water that flows in natural channels and all other water that has or acquires the capacity to satisfy uses of general interest, navigable lakes, lake beds, the inner shores of rivers and the watersheds that originate in the property of one owner and end in the property of another.

Groundwater is also of public domain without prejudice to the rights of the owner of the property above it to extract it according to their interests and in accordance with local regulations. In special cases and under particular restrictions, it gives the land owner the right to water that does not have nor acquires the aptitude to satisfy needs of general interest.

The provinces and the Subsecretaría de Recursos Hídricos de la Nación (Subsecretariate of National Hydric Resources) created the Consejo Hídrico Federal (COHIFE) (Federal Hydric Council) (Law 26438) to coordinate federal hydric policy and to combine policies, legislation and management of water in jurisdictions. The Federal Council for the Environment coordinates the activities of the national and provincial governments on matters of environmental policy (Law 25675).

The so-called "Guiding Principles for Hydric Policy of the Argentine Republic" propose a conceptual base for efficient and sustainable management of hydric resources in the entire country. These principles are the direct result of several years' work by sectors involved in the use, management and protection of water resources that were summoned by the argentine provinces at the request of the Subsecretaría de Recursos Hídricos de la Nación (National Sub-secretariat of Water Resources) (originally created as the Secretariat of Water Resources). Simultaneously, the Fundamentos del Acuerdo Federal del Agua (Foundations for the Federal Agreement on Water) which gave rise to al COHIFE, proposed that the National Congress should sanction a coherent and effective Framework Law for Water Policy, that combines provincial, regional and national interests respecting the historical roots of each jurisdiction.

The domain of province over water is a primary (National Constitution, Art. 124), public (Civil Code Art. 2340), and residual right which recognizes limitations. Therefore provinces must manage or allow the management of water in accordance to the Civil Code (Arts. 2636/2653) although in some cases water management is under national jurisdiction, such as navigation and electricity interconnection (Law 15336, Art. 12).

The water rights granted to individuals by the civil code are those exercised on the grounds of the legal requirements it establishes. They are basically enforced by local authorities in agreement with matters of federal competence exercised by the National Government.

Certain provinces fix basic hydric policy principals in their constitutions, with the purpose of making them prevail over a contrary decision by any of its three powers. Nevertheless, while executing their regulatory faculties regarding management, use and preservation of both public and private water under their jurisdiction, provinces have sanctioned laws that often overlap and in other cases are contradictory and have ascribed application to a variety of agencies.

To face the inconveniencies provoked by such dispersal, some provinces bring these norms together in water codes and unify their application in a central agency. Some provinces, accepting the paradigm of integrated and per basin management, have created agencies to manage development or exercise authority in a certain basin or in the part of it that falls under its jurisdiction.

The Constitution grants the provinces original domain over rivers (Art, 124), while the Civil Code grants public domain (Sec. 2340, Sub-sec. 1), however it does not typify the relation between several provinces bathed by the same waters (Appendix I)

In light of the aforementioned, the following conclusions can be reached:

- The legal system in Argentina deals with a multitude of water-related issues. The abundant and scattered norms from 25 jurisdictions and some interjurisdictional sources concerning the preservation and improvement of watersheds and conferring their application to numerous organisms, creates problems regarding the identification and application of norms, while stimulating certain activities but not others. This rarely helps to solve issues, it more likely increases conflict of interests generated by permanent circulation of water throughout basins, decreases water availability and worsens the effect of its over-abundance. On a national scale, this is even more obvious because a national body for water regulation is lacking. At the launching of the "Guiding Principle for Water Policy in the Argentine Republic", within the Hydric Policy of August 8, 2003, the following was stated: "The standardization of Guiding Principles through a Framework Law on behalf of the National Congress will allow the stating of clear and equitable rules that shall provide legal certainty, thus avoiding proliferation of partial, disperse, overlapping and often contradictory legislations".

- There has been a consensus to sanction a national regulatory body for water, or at least to codify federal hydric legislation for quite some time. Likewise, the National Constitution authorizes the National Congress to condense national norms regarding water into a national body.

- A National Law or Code for Water would provide rights derived from the constitution for the rational use of water and natural resources and the conservation of natural wealth. The "Consejo Hídrico Federal" (COHIFE) (Federal Hydric Council) a federal authority for normative coordination, is showing the signs of becoming the most adequate organ to create such a law or code, because it anticipates the consensus of the entire political and administrative system as well as its obstacles. In addition, COHIFE promotes the Guiding Principles for Hydric Policy of the Argentine Republic.

- The abundance and scattering of norms is also present in the international laws for water, built from precise agreements. The location of Argentina in the lower section of the Plata Basin and the opportunities offered by the Andean rivers force it to continue ahead in the building of an equitable and solidary international legal system for water.

8. Glossary

Alluvium. Detrital material such as gravel, sand and clay, deposited by water currents.

Anthropic. Anything associated to, influenced by, belonging to, or even contemporary to the human species or human being.

Aquaculture. The commercial cultivation of aquatic organisms, either plants or animals (Tundisi, 2009).

Aquifer . An aquifer is a permeable stratum or geological formation that allows groundwater circulation and storage through its pores and crevices. Within these formations a wide variety of materials can be found such as river gravel, silt, highly cracked limestone, poorly cemented porous sandstone, beach sand, some volcanic formations, dune deposits and even certain types of clay. The upper level of groundwater is called the water table, and in the case of an unconfined aquifer, it is the phreatic level. In an artesian aquifer groundwater is confined by impermeable layers and its water is under positive pressure.

Biodiversity. The wide variety of living things (plants and animals) on Earth and the natural patterns it is made of.

Biota. In its most common use, the word "biota" is the name given to the group of plant and animal species occupying a given area. The term European biota is used to refer to the list of species living in the European territory. Biota can be divided into flora and fauna. The concept can be extended to refer to the species in a section of the ecosystem such as the soil, or rhizosphere, or the bottom of an aquatic ecosystem.

Desalinization. Physical or chemical process to eliminate salt from salt water (from the ocean or salt lakes) to produce fresh water.

Draft. The draft of a ship or boat is the vertical distance between the waterline and the keel or baseline, including the thickness of the hull; in the case in which the thickness is not included, the draft outline would be obtained.

Dredging. Dredging is the removal of sediments from a watercourse, lake, bay, or the entrance to a port, to deepen a navigable channel or river, to increase its capacity to hold water (thus avoiding floods upriver), or to aid ship traffic and avoid the risk of grounding.

Eutrophication. In Ecology, eutrophication is the name given to the process of nutrient enrichment of an ecosystem. It is widely used in reference to the contribution of additional nutrients (nitrogen and phosphorus) from point sources (isolated discharge) or diffuse sources (extensive spillage from a variety of land uses). A eutrophized ecosystem or environment is characterized by an abnormally high amount of nutrients, followed by an increase in biomass and its disposal.

Evapotranspiration. Evapotranspiration is the loss of water from a surface by direct evaporation plus the loss of water through transpiration in plants. It is measured as mm per unit of time.

Externalities. In Economics, an externality is a benefit or cost that is not reflected in the price received or incurred by a physical or moral party who did not agree to the action causing the cost or benefit. A benefit is called a positive externality while a cost is considered a negative externality.

Fluvial regimen. The type of fluvial regimen is determined by the way a river flow is fed. This can basically be nival also called glacial or snowmelt, when it comes from the melting of snow, or pluvial when coming from precipitation. Mixed forms arise from the combination of these two, such as nivo-pluvial or pluvio-nival depending on which of the two predominates. The type of regimen influences flow variations and the regularity of the river. A nival or glacial regimen has its maximum flow in the spring and beginning of summer, as this is when snow melts, while minimum flow occurs in the winter. A pluvial regimen increases flow with rains and

temperature, and its regularity depends on the season when precipitation is greatest. It is predominant in tropical, sub-tropical areas, as well as in some template areas.
Likewise, a mixed regimen predominates in a great part of template areas, where the time of lowest flow coincides with fall-winter. Rivers with this kind have the most balanced flow. Irregular displays of pluvial regimens depend on sporadic precipitations that produce torrential currents and floods.

Food chains. The transfer of energy in foodstuffs through a series of organisms in which one feeds on the one before it and is the food of the following.

Hydric resources. Hydric resources are one of the most important natural resources for life; so much so that recent investigations on the Solar System look for traces of water on other planets and satellites as an indicator of the possible existence of life forms on them.

Hydric stress. Hydric stress occurs when water demand is greater than water supply during a specific period or when its use is restricted due to its poor quality. Hydric stress causes deterioration of freshwater quantity (over-exploited aquifers, dry rivers, etc.) and quality (eutrophication, pollution by organic matter, saline intrusion, etc.).

Hydric tension. A country is under hydric tension when its annual supply of fresh water is between 1,000 and 1,700 m^3 per person. Countries in these conditions probably experience temporary or limited water scarcity.
Hydroarsenicism. Environmental disease the origin of which is associated to the use of arsenic-contaminated water. In certain regions of the world, it is endemic.

Hydrologic cycle. The water cycle in an orographic basin, continent or the entire planet; it represents a process and balance of precipitation, infiltration, evapotranspiration and flow or retention of surface and groundwater.

Improved sanitation. Improved sanitation is defined as one that guarantees hygienically separating human excreta from human contact. However, this excludes sharing sanitary facilities between several households or public facilities. The following are included in improved sanitation: (a) flush toilet/latrine (a.1) piped sewer system, (a.2) septic tank, (a.3) flush/pour flush to pit latrine; (b) ventilated improved pit latrine; (c) pit latrine with slab, and (d) composting toilet. The following are examples of unimproved sanitation: (a) flush/pour to elsewhere; (b) pit latrine without slab; (c) bucket; (d) hanging toilet or hanging latrine, y (e) no facilities or bush or field campo (open-air defecation) (JMP, 2010).

Improved water (source of). Water that comes from or is supplied by a source or mains that protects it from external contamination because of the way it is constructed and designed, especially from fecal matter. Among improved sources of water there are: (a) piped water into dwelling, yard or plot, (b) public tap or standpipe, (c) tubewell or borehole, (d) protected dug well, (e) protected springs and (f) rainwater collection. Among non-improved sources there are: (a) unprotected dug well, (b) unprotected spring, (c) cart with small tank/drum, (d) tanker-truck, (e) surface water (river, reservoir, lake, lagoon, stream, canal, irrigation canal), y (f) bottled water (Bottled water is considered improved only when the household uses other sources of water to cook and for personal hygiene; wherever this information is not available, bottled water is classified case by case) (JMP, 2010).

Inter-basin diversion. Inter-basin diversions are projects for the transfer of water to increase flow within the receiving basin.

Leaching. Process in which a liquid solvent comes into contact with a pulverized solid producing a solution of one of the components of the solid.

Micro-measurement. Group of measuring activities to know the volumes of water used by the population. This information can be obtained per system, sector and eventually per subsector; in addition it can be classified as commercial, residential, touristic, etc.

Monitoring. Process to determine physical, chemical and biological variables in an ecosystem to allow the construction of data bases and an information system (Tundisi, 2009).

Non-irrigated crops. Non-irrigated crops are those which are not irrigated by man, as they only rely on rainwater.

Precipitation. In meteorology precipitation is any form of hydrometeor falling from the sky and reaching the earth's surface. This includes rain, drizzle, snow, sleet, and hail, but excludes virga, mist and dew because these are forms of condensation, not precipitation. The amount of precipitation on a specific point of the earth's surface is called pluviosity or pluviometric amount. Precipitation is a major component of the water cycle. It is responsible for depositing freshwater on our planet, and consequently for both plant and animal life. It is produced by clouds when they reach the saturation point of vapor, which is when droplets of water increase in size to the point they precipitate by gravity. It is possible to inseminate clouds to induce precipitation by spraying a fine powder or an adequate chemical (such as silver nitrate) within the cloud, thus accelerating the formation of droplets and increasing the probability of precipitation; these tests however have not been satisfactory in practically all cases.

Reservoir. A reservoir is an accumulation of water produced by the obstruction of a river bed which totally or partially closes its flow. The obstruction can be caused by works built by man for this purpose, such as dams, or by natural causes such as a landslide on a narrow stretch of a river or stream or the accumulation of ice plates.

Salinization. Salinization is often produced by excessive soil irrigation. As water evaporates on the surface, it deposits salts from rocks and underground layers. These salts crystalize and interfere in the development of roots.

Sanitary deficit. Lack of access to basic sanitary services.

Sanitary deficit index. A combination of characteristics concerning individuals and their surroundings, such as a) access to basic sanitary services and b) accessibility to public health systems; it is useful to classify the vulnerability of public health in a region.

Seasonal reservoirs. A type of reservoir with the capacity to store water during the rainy season to regulate it efficiently and make it available according to demand during the dry or drought season.

Sustainability. In Ecology, the term "sustainability" describes how biological systems are kept diverse and productive through time. It refers to the balance of a species with its surrounding resources. It also applies to the exploitation of a resource below the limit for its renewal.

Sustainable development. The process of increasing and long-lasting improvement in the life of a human community. It can occur along one or more aspects such as physical (health, nutrition, housing, jobs, services, infrastructure), financial, ethical, spiritual and emotional (education, recreation, art, culture, religion). In socio-economic and cultural terms, sustainable development occurs when progress and consolidated quality of life continues through time. From the perspective of prosperity, human equity and environmental conservation, according to the 1987 Brundtland report, sustainability is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Virtual water. This concept developed in the early 1990's. Because water is necessary to produce commodities and services, the virtual water of a product, whether agricultural or industrial, refers to the water needed to make it. Virtual water is a tool to calculate the actual use of water in a country or its water footprint, and it is equal to the total water resulting from domestic consumption plus the virtual water from other countries, minus the virtual water it exports to other countries, The water footprint of a country is a useful indicator of a country's consumption of the world's water resources.

Water. A substance with a molecule formed by two atoms of hydrogen and one atom of oxygen (H2O). It is essential for the survival of all known forms of life. The term "water" generally refers to the substance in liquid state, although it can be found as a solid called ice, and as a gas known as vapor.

Water scarcity. A country suffers water scarcity when the annual fresh water supply is lower than 1,000 m^3 per person. Such a country probably experiments chronic and lengthy water scarcity conditions that hinder its development.

Water treatment. In environmental engineering, the term "water treatment" is the group of physical, chemical or biological operations aimed at eliminating or decreasing pollution or unwanted characteristics of water of various kinds: natural, for supply, residual, or in the case of urban wastes, raw sewage. The purpose is to obtain water with the proper characteristics for the use it will be given, thus the exact nature and combination of processes varies not only with the traits of the original water, but also with its final use.

Wetlands. Areas of the Earth's surface temporarily or permanently flooded, regulated by climate factors and in constant relation with the living things that inhabit them. They are highly biodiverse and vulnerable to human activity.

9. Acronyms

A.D.E.R.A.S.A.
Asociación de Entes Reguladores de Agua y Saneamiento de las Américas (Association of Entities for Water Regulation and Sanitation

A.M.B.A.
Area Metropolitana de Buenos Aires (Buenos Aires Metropolitan Area)

A.N.C.E.
Academia Nacional de Ciencias Económicas (National Academy for Economic Sciences)

A.N.C.E.F y N.
Academia Nacional de Ciencias Exactas,Físicas y Naturales (National Academy for Exact, Physical and Natural Sciences)

A.N.I.
Academia Nacional de Ingeniería (National Academy of Engineering

A.P. y S.
Agua Potable y Saneamiento (Clean Water and Sanitation)

Arg.Cap.Net
Red Argentina de Capacitación y Fortaleci-miento de la Gestión Integrada de los Recur-sos Hídricos (Argentine Network for the Training and Strengthening of Integrated Management of Hydric Resources)

AySA
Agua y Saneamientos Argentinos (Argentine Water and Sanitation)

EPA
Environmental Protection Agency (USA)

GEI
Gases de efectos invernadero (greenhouse gases)

GIRH
Gestión Integrada de los Recursos Hídricos (Integrated Management of Hydric Resources)

IANAS
Inter-American Network of Academies of Sciences

ILEC
International Lake Environment Committee

INDEC
Instituto Nacional de Estadísticas y Censos (National Institute for Statistics and Census

O.S.N.
Obras Sanitarias de la Nación (National Sanitary Works)
O y M (O&M)
Operación y Mantenimiento (operation and management)

P.A.H.O
Pan American Health Organization

UNICEF
United Nations Children's Fund

W.H.O.
World Health Organization

10. References

1. "2° Informe de las Naciones Unidas sobre el desarrollo de los recursos hídricos en el mundo", 2006.
2. "2° Comunicación Nacional de la República Argentina a la Convención Marco de las Naciones Unidas sobre el Cambio Climático", 2007.
3. IV Congreso Ibérico de Gestión y Planificación del Agua, 2004.
4. ADERASA. Asociación de Entes Reguladores de Agua Potable y Saneamiento de las Américas, "Informe Anual de Benchmarking 2010. Informe Preliminar", 2010.
5. Aisiks, E. G. "La gran crecida del río Paraná de 1983", Organización Techint Boletín Informativo, 232, Buenos Aires, 1984.
6. Asociación Federal de Entes Reguladores de Agua y Saneamiento (AFERAS), 2010. Conclusiones de los Seminarios de Tarifas y Sistemas Tarifarios de AFERAS (2009-2010).
7. Banco Interamericano de Desarrollo."Agua Potable, Saneamiento y los Objetivos de las Metas del Milenio en América Latina y el Caribe", 2010.
8. Bereciartua, P. J. "Vulnerability to global environmental changes in Argentina: opportunities for upgrading regional water resources management strategies", Water Science & Technology, Vol 51, N° 5, pp. 97-103, IWA Publishing, 2005.
9. Berz, G. "Flood disasters: lessons from the past - worries for the future", Geoscience Research Group, Munich Reinsurance Company, Alemania, 1999.
10. Bianchi, H. y Lopardo, R.A. "Diagnosis and Mitigation of Groundwater Level Rise in a Highly Populated Urban System", XXX IAHR Congress, Vol. B, pp. 629-636, Thessaloniki, Grecia, 2003.
11. BID. "Water and Millennium Development Goals: Investment Needs in Latin American and the Caribbean", 2005, 2007.
12. Boj, C. A. "Principales Consideraciones sobre la operación de Embalses Estacionales", Comisión Nacional de Energía Eléctrica. Guatemala, C.A.
13. Calcagno, A., Mendiburo, N. y Gaviño Novillo, M. "Informe sobre la Gestión del Agua en la República Argentina", World Water Vision, 2000.
14. CEDLAS-Banco Mundial. Socio-economic Data Base for Latin America and the Caribbean-SEDLAC-, 2009.
15. Cham, R. "Diagnóstico de la situación de los servicios de agua potable y saneamiento en relación con los objetivos de desarrollo del milenio", Banco Interamericano de Desarrollo, 2007.
16. Conferencia Internacional sobre el Agua y el Medio Ambiente (CIAMA), Dublin, 1992.
17. Del Castillo, Lilian. "Los pasos del agua" (De Mar del Plata a Estambul 1977-2009), CARI, Documento de trabajo N° 86, Buenos Aires, 2009.
18. Escalante Sandoval, Carlos A. "La vulnerabilidad ante los extremos: la sequía", Revista Ingeniería Hidráulica de México, México, 2003.
19. Estudio Análisis de la Situación Sanitaria en el Área del Proyecto de Alcantarillado en el Partido de la Matanza, Provincia de Buenos Aires

(Programa BID 1059-oc/ar) del Comité Ejecutor del Plan de Gestión Ambiental y de Manejo de la Cuenca Hídrica Matanza Riachuelo, 2004.
20. FAO. "AQUASTAT", 2005.
21. FAO. "Agua y Cultivos". Roma, 2002.
22. FAO/Banco Mundial. "Agricultura mundial: hacia 2015/2030", 1995.
23. FAO. "Programa de Acción Internacional sobre el Agua y el Desarrollo Agrícola Sostenible", Roma, 1990.
24. Fay, Marianne and Mary Robinson. "Infrastructure in Latin America and the Caribbean Recent Development and Key Challenges". The World Bank, 2006.
25. Fernández, D., Jouravlev, A., Lentini, E. y Yurquina, A. "Contabilidad regulatoria, sustentabilidad financiera y gestión mancomunada: temas relevantes en servicios de agua y saneamiento", Serie Recursos Naturales e Infraestructura N° 146, CEPAL, Santiago, 2009.
26. Global Water Partnership, "Integrated water resources management", 2000.
27. Goniadzki, Dora. "Sistemas de información y alerta hidrológico. La prestación de un servicio esencial", Revista INA, Año 1, N° 1, pp. 21-23, 1997.
28. Grupo Banco Mundial. "El Banco Mundial y el suministro de agua y saneamiento en América Latina y el Caribe", 2006.
29. http://www.cavaargentina.com (consultada en octubre de 2010)
30. http://www.expozaragoza2008.es (consultada en octubre de 2010)
31. http://www.greenfacts.org (consultada en octubre de 2010)
32. http://www.hydriaweb.com.ar (consultada en octubre de 2010)
33. http://www.natureduca.com (consultada en octubre de 2010)
34. Hutton, G. y Haller, L. "Evaluación de Costos y Beneficios por mejoras de los servicios de Agua y Saneamiento- Organización Mundial de la Salud", 2004.
35. HydroPower&Dams. World Atlas & Industry Guide, 2007.
36. INDEC. "Estadísticas de Población y Hogares", IV Trimestre, 2006.
37. Informe Bruntland. Report of the World Commission on Environment and Development: Our Common Future. Naciones Unidas, 1987.
38. Informes Anuales. "Agua y Saneamiento Argentinos SA".
39. INCYTH-UNESCO. "Balance Hídrico de la República Argentina", Buenos Aires, Argentina, 1994.
40. JMP (Joint Monitoring Program). "Progress on Sanitation and Drinking-water: 2010", Update, 2010.
41. Lentini, E. "Servicios de agua potable y saneamiento: lecciones de experiencias relevantes", CEPAL, en edición, 2010.
42. Lopardo, R. A. y Seoane, R. "Algunas reflexiones sobre crecidas e inundaciones", Ingeniería del Agua, Vol. 7, N° 1, isbn 1134-2196, pp. 11-21, Valencia, España, 2000.
43. Martinez, S. y Bauer, C. "The lakes and environmental education", en Memorie dell'Istituto Italiano di Idrobiologia, pp. 39 a 54, Verbania Pallanza, Italia, 1993.
44. Martinez, S., Bauer, C. and Calcagno,

A. "Experiences of ILEC-PEAEL Project in Argentina", en "Guidelines of Lake Management: A focus on Lakes/Rivers in Environmental Education", pp. 63 a 67. Environment Agency, Government of Japan, Tokio, Japón, 1998.
45. Menéndez, A. "La comprensión de la fenomenología de las inundaciones como requisito para su control", Revista INA, Año II, diciembre, pp. 25-28, 1998.
46. Moreno, Ana Rosa. "Agua, Cambio Climático y sus Efectos en Salud Humana", México Simposio Agua, Clima y Salud.
47. Murillo, J.A. "The scourge of scour, Civil Engineering", pp. 66-68, New York, 1987.
48. OMS/UNICEF: Organización Mundial de la Salud y Fondo de las Naciones Unidas para la Infancia. "Programa Conjunto de Monitoreo de Provisión de Agua y Saneamiento. Progresos en materia de agua y saneamiento, Enfoque especial en el saneamiento", Ginebra, 2008.
49. ONU. "El agua, una responsabilidad compartida", Segundo informe sobre el desarrollo de los recursos hídricos en el mundo, 2006.
50. Ordoqui Urcelay, M.B. "Servicios de agua potable y alcantarillado en la ciudad de Buenos Aires, Argentina: factores determinantes de la sustentabilidad y el desempeño", Serie Recursos Naturales e Infraestructura 126, CEPAL, Santiago, 2007.
51. Organización de la Naciones Unidas. Declaración de Río Cumbre Mundial 1992.
52. Paoli, C. "Inundaciones en ríos con creciente ocupación", Revista INA, N°1, pp. 78-81, 1997.
53. PNUD. "Informe sobre Desarrollo Humano Más allá de la escasez: Poder, pobreza y la crisis mundial del agua", publicado para el Programa de las Naciones Unidas para el Desarrollo, 2006.
54. PNUMA. "Perspectiva mundial del medio ambiente 2000 recursos hídricos". Nairoby, Kenia, 1999.
55. Prüss-Üstün, A., Bos, R., Gore, F., Bartram, J. "Safer water, better health: costs, benefits and sustainability of interventions to protect and promote health", World Health Organization, Geneva, 2008.
56. Ramsar. "Disponibilidad del agua", 2008.
57. Repetto, R. "Skimming the water: rent-seeking and the performance of public irrigation systems", Research Report No 4, 1986.
58. Revista Hydria. "Arsénico. Desafíos sanitarios por un contaminante natural", N°1, 2008.
59. Revista INA. "Inundaciones en ríos con creciente ocupación", N°1, pp. 78-81, Paoli, C. 1997.
60. Sachs, Jeffrey. "Economía para un planeta abarrotado", Editorial Sudamericana, Buenos Aires, Argentina, 2008.
61. Schneier-Madanes, G. "L'eau mondialisée: la gouvernance en question", La Découverte, París, 2010.
62. Segundo informe de las Naciones Unidas sobre el desarrollo de los recursos hídricos en el mundo. "El agua, una responsabilidad compartida", 2006.

63. Triano, María Soledad. "Mapa de Población con déficit sanitario de la República Argentina, 2001", FLACSO/ CEDES, 2006.
64. Tribunal Latinoamericano del Agua 2009.
65. Tundisi, J. G. y Matsumara Tundisi, T. "A Água", pp. 106, Sao Paulo, Brasil, 2005.
66. PNUMA. "Perspectiva mundial del medio ambiente 2000 recursos hídricos", Nairoby, Kenia, 1999.
67. UNESCO. "2003, año internacional del agua dulce", 2003.
68. UNESCO. "Agua para el futuro: ¿Cuáles son las tendencias?", 2003.
69. UNESCO. "Engineering: Issues, Challenges and Oportunities for Development" Report published by UNESCO, Paris, France, 2010.
70. Zorrilla, S. "Lineamientos para la estrategia de apoyo al sector Agua potable y saneamiento", CETI – BID, 2008.

Isla del Sol - Titicaca

Water Resources in Bolivia

A Strategic Viewpoint of the Issues Associated with Transboundary Waters

Fernando Urquidi Barrau, Ph. D.
Academia Nacional de Ciencias de Bolivia

1. Introduction

In the XXI century, the scarcity of freshwater (blue water) is one of the most significant threats that will affect humanity worldwide. Freshwater has become an increasingly scarce and vulnerable natural resource. Global climate change is causing mountain snow and polar ice to melt, while altering local and regional hydrologic cycles. These changes have caused disequilibrium between overabundance and scarcity of the water resources throughout the world, which is very difficult to manage and to solve. This dramatic situation is worsened by the poor and irrational administration and management exercised by mankind of all the natural resources, including water.

Bolivia has abundant freshwater, occupying the twentieth position amongst world's nations with high hydrologic balances. In addition, it is one of the countries with the largest freshwater supply per capita in Latin America, approximately 50,000 cubic meter/capita/year. However, the surface and underground water balances of its four major hydrological basins, have not been fully quantified nor explored. Water is not evenly distributed in the country; while there are areas with great availability of water and high annual precipitation, in nearly half of its territory this resource is scarce and there is a great deficit of it, reaching desert levels. Additionally, the country suffers with droughts, hailstorms, floods and other weather phenomena every year, and in many cases unpredictably. These climate phenomena is worsened by events like El Niño and La Niña. Bolivia is an inland country with a surface area of 1,098,581 Sq. Kms and no more than ten million inhabitants. Bolivia has 6,918 Kms of international borders with five different countries: 3,424 Kms with Brazil, 741 Kms with Paraguay, 773 Kms with Argentina, 850 Kms with Chile and 1,131Kms with Peru. Of these, 3,442 Kms (49.8% of the total) are water, fluvial or lake arcifinious boundaries (Montes de Oca, 2005). Through the vast aquatic borders, the controversy over the rights and uses of the shared and contiguous water is inevitable, and leads to transboundary water issues that require permanent management and surveillance to quickly solve international disagreements or disputes. For this reason, whatever is decided for upstream water will have direct incidence on what is negotiatied downstream. Additonally, the continuous increase in the direct demand of water resource, especially from the mining, agriculture and hydroelectric generating industries of the neighboring countries, is causing transborder water conflicts.

The Amazon River macro-basin, for example, occupies 65.9 % of the national territory and has a border of 2,464 Kms, 35.6% of the country's total international boundaries. Nearly 85% of these are aquatic arciniferous boundaries of contiguous waterways, of which an estimated 70% are mostly abandoned and have an extremely scarce bolivian population. The cities of Cobija (population 38,000), on the Acre River, and Guayaramerín (population 47,000), on the Mamoré River (Madera River), are the two largest population settlements on this vast aquatic boundary . It is mainly an upstream country and is also a downstream country, but in a minor scale. As an upstream country, its waters run towards neighboring nations along the macro-basins of the rivers Amazon (Brazil) and Río de la Plata (Argentina and Paraguay), and Pacific Ocean (Chile). In addition, it recieves downstream water in the Altiplano or Endorheic macro-basin, specifically in Lake Titicaca (Peru) and the rivers Mauri (Maure in Peru) and Lauca (Chile) and in the amazonic macro-basin, through the river Madre de Dios (Peru).

Transboundary water resources must be analyzed from various perspectives, including scientific-technical, legal, institutional and social aspects. Likewise, it requires greater involvement of social actors on both sides of the borders. From the scientific-technical point of view, Bolivia needs greater knowledge and data, not only of the four major national water basins, but also of the surface and underground water it shares with neighboring countries. In addition, the Bolivian Government has a reduced financial capacity to satisfy the scientific and technological studies necessary to learn in detail about the size of flow, the physical and chemical characteristics of the water resources present in its boundaries. Nevertheless, this technical-scientific viewpoint, with obvious limitations, is the main topic of the present study regarding the problems associated with Bolivian transboundary waters.

From the legal viewpoint, the nation must consider the new Political Constitution of the Nation, enacted on February 7th, 2009, as well as the urgent need to analyze and to enact complementary laws to rationally regulate water resources. These new laws must replace the obsolete Water Law of October 26th, 1906, and reconcile the relevant current and future bilateral and sub-regional agreements. From an institutional perspective, the new executive structure and multinational legislative instances must be adapted to the Bolivian participation on international entities, and bilateral or trilateral commissions.

The current governmental policies, found in Articles 373 to 377 of the new Political Constitution of the Nation, consider water as the most fundamental right for the people's sovereignty and life, and its use must be done in accordance to traditional ways and customs. Water in all of its states, including surface and underground water, is finite, vulnerable and a strategic resource. It also has a social, cultural and environmental purpose. It cannot be subject to private acquisition, and with the service it provides, will not be subject to concession and will be regulated in accordance to the law (this law should be proposed and promulgated in the coming years to replace the 1906 Water Law). In summary, to-day, water cannot be considered a commercial good. Nevertheless, the accelerated growth of urban population (65% of the total Bolivian population), and the needs of certain industries, have caused a higher demand of potable water and its services. This dilemma is difficult to solve in the near future, if water is not considered a commercial good, in one way or another.

With respect to international relations with border countries, Article 377 of the Political Constitution must be fulfilled, as it stipulates that the State will permanently protect boundary and transboundary waters, to conserve the hydrological wealth and to contribute to the integration of the people in both sides of the frontiers. We must highlight that Bolivia is a signatory of the 1933 Act of Montevideo, which refers to the industrial and agricultural uses of international rivers. It's also a signatory of the 1966 Helsinki Norms and the Ramsar Convention on the international importance of wetlands enforced since 1975. However, Bolivia is not a signatory of the two most important conventions on surface and underground water: the United Nations Convention on the Law of Non-Navigational Uses of International Watercourses (1977) and the Convention on Transboundary Aquifers. The latter is still under discussion and has not yet been approved or implemented by the UN General Assembly. The problems associated in Bolivia to surface and underground boundary waters have been present since the foundation of the nation in 1825. These issues and problems should be dealt by joint bilateral studies for each specific case, and the political response should be completely consistent with them.

Public actions taken with respect to water issues should be guaranteed by politicians and private citizens, as well as social movements. Hydrological resources are fragile and have a high political and social content, partly because the Bolivian rural original peasant population (35% of the total) considers water as a divine unconditional gift given as rain. The social and economic emphasis should be analyzed in a balanced, fair and impartial way to obtain the greatest benefit of water resources for the entire country.

Water has a strategic value for the future of Bolivia and thus hydrological resources should be an instrument of power and negotiation in its relations with neighboring countries. The bilateral, trilateral and regional treaties subscribed by Bolivia in recent decades should serve as a base and an example for future negotiations. These negotiations should continue with strong emphasis on the environment and must allow sustainable development of those regions and municipalities in the country that are involved or affected by them. Water must contribute Bolivia's permanent fight against poverty and social exclusion. In summary, not only the quantity but also the quality of water must effectively contribute to the sustainable development and growth of the nation.

2. Water Availability in Bolivia

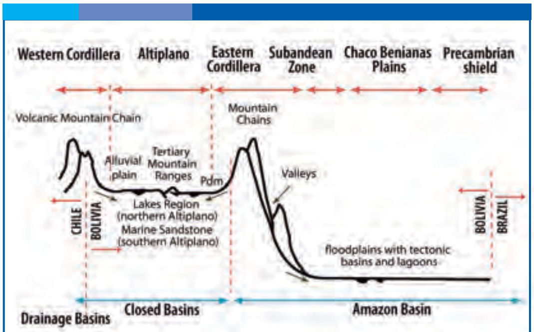
In order to discuss the strategic scientific and technical aspects of the issues concerning Bolivia's transboundary water, it is necessary to provide a brief description of the country's hydrological resources, and to describe the referential geographic context and its relation with neighboring countries. Likewise, it is important to properly define the most adequate units to handle and manage hydrological resources within the existent hydro-physiographic framework.

2.1 Hydro-physiography of Bolivia

The hydro-physiography of Bolivia is made up of two major units and seven physiographic provinces. The western major unit is defined by the high ground of the Central Andes Cordillera, about 38% of the territory, and the rest of the country by the eastern major unit, which consist of the lower ground of the Amazon and Chaco alluvial plains, 62% of the total territory. The Andean block in Bolivia consist of three contiguous morphotectonic provinces, which are, from west to east, the Cordillera Occidental (Eastern Cordillera), the Bolivian Altiplano and the Cordillera Oriental (Western Cordillera). The Altiplano is a series of high, intermontane basins with an average altitude of 4,000 meters. To the east of the Cordillera Oriental, the Sierras Subandinas (Subandean Sierras) and the Valles (Valleys) are found. The second major unit is located in the eastern and northeastern areas of the country and consist of the alluvial Amazon plains along the Brazilian Precambrian Shield and to the southeast the Bolivian Chaco plains. The physiographic provinces shown in FIG. 1 and FIG. 2 are divided into subunits, which provide a general summary of the relief and geological characteristics of the land.

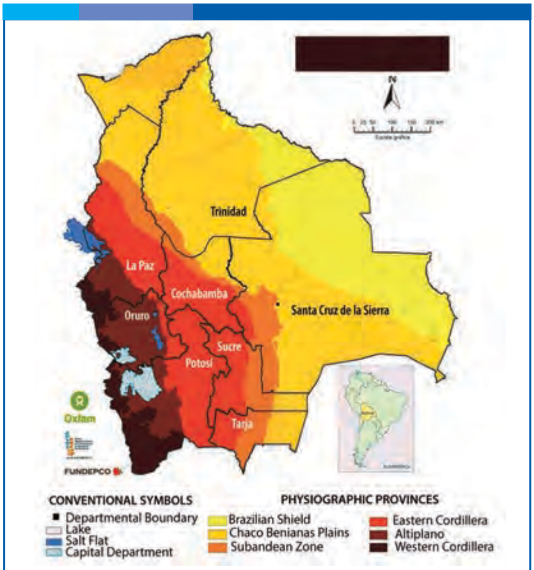
2.2 Climatic Conditions

The availability of water in Bolivia is directly related to its geographical position within the northern equatorial region and the



SOURCE: ANA 2009

FIG. 1. Physiographic Provinces and Hydrographic Basins

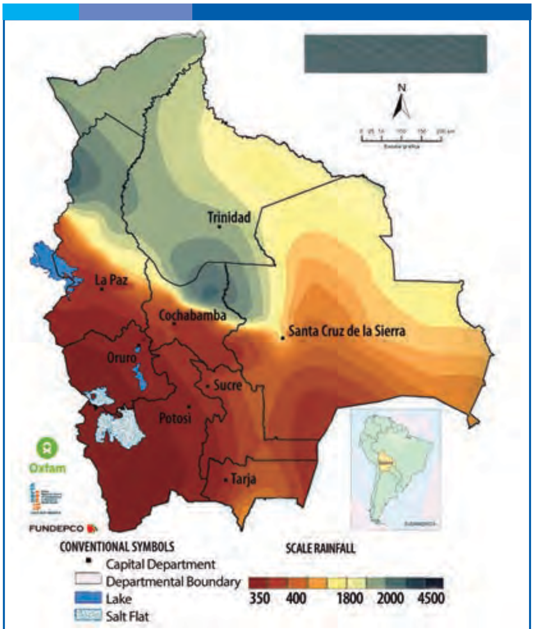


SOURCE: ATLAS AMENAZAS, VULNERABILIDADES Y RIEGOS DE BOLIVIA - 2008

FIG. 2. The twelve Hydrographic Watersheds of Brazil

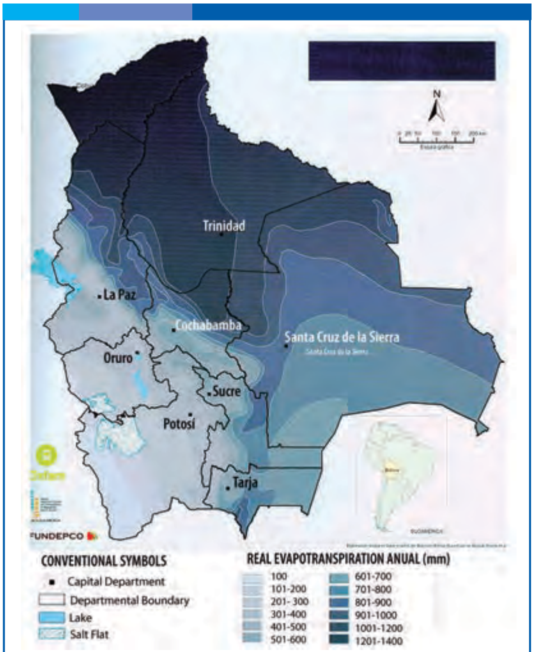
weather conditions present in the various hydro-physiographic areas. These areas are influenced by macro-weather, micro-weather and local weather events. The macro-weather conditions are characterized by the strong seasonality of precipitation. In the country as a whole, the rain pattern is tropical and the greatest precipitation occurs during the warmer months of the year. Bolivia is located between two zonal atmospheric flows: the Intertropical Convergence Zone (ITCZ) and the Subtropical High Pressure Belt of the Southern Hemisphere. This global weather mechanism is influenced by southern cold advection winds (surazos) from the South Pole and the thermal variations of the eastern Pacific Ocean known as El Niño and La Niña. Of the 855 weather stations in the country, 496 are found in the Amazon basin, 142 in the Endorheic basin and 217 in the Rio de la Plata basin. The Pacific macro-basin had only one weather station near Laguna Colorada, which operated from 1985 through 1997. According to Montes de Oca (2005), the distribution of average annual temperatures in the country varies with altitude from close to 25°C in the plains, to 18°C in the valleys and 10°C in the high plateaus. The annual temperature variation is slight as the length of day and angle of solar incidence is very similar during the winter and summer. The lowest temperatures occur in June and July, in the middle of the winter, towards the early morning. The climatic conditions are significantly modified by local phenomena and microclimate, such as the orientation of the ridges, the presence of lakes, vegetation cover, etc., all them affect the temperature and precipitation. Along the entire national territory there are two rainy periods, one during the summer with more abundant precipitation (due to the fall in the Intertropical Convergence Zone) and another during the winter with less abundant rainfall (the northern movement of the Intertropical Convergence Zone produces movement of dry and stable air). The rainy season is basically during the summer, starting in December and ending in March, with a maximum during January, followed by February. From 60 to 80% of rain falls during these four months. Winter is the dry season, with minimal precipitation from May to August. These two seasons are separated by transition periods, one in April and another from September to October.

The map for normal precipitation, FIG. 3, shows that the southwest corner of the country is the driest, with less than 100 mm of rain per year. The Eastern Cordillera receives between 350 and 500 mm of rain/year. The Bolivian Altiplano is dry, with a rainfall of 100 to 350 mm/year. The area next to Lake



SOURCE: ATLAS AMENAZAS, VULNERABILIDADES Y RIEGOS DE BOLIVIA - 2008

FIG. 3. Spatial distribution of specific discharge in Brazil

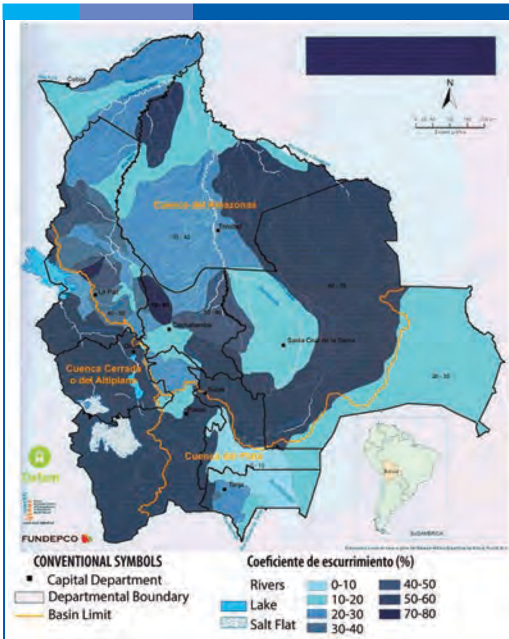


SOURCE: ATLAS AMENAZAS, VULNERABILIDADES Y RIEGOS DE BOLIVIA - 2008

FIG. 4. Recharge Area of the Main Aquifers in Brazil

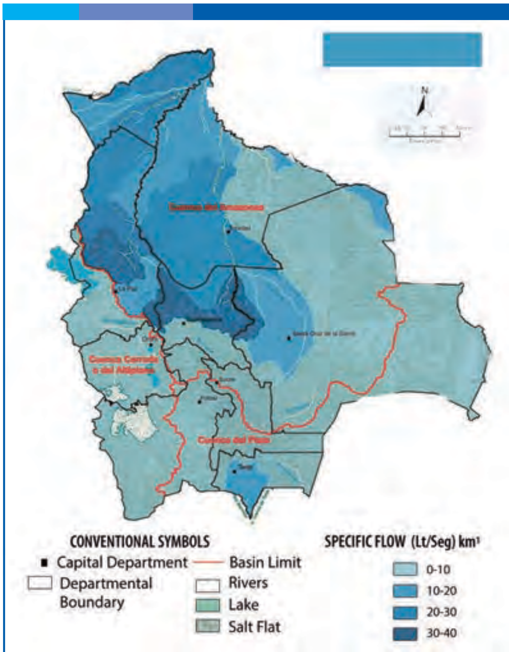
Titicaca exceptionally receives from 500 to 700 mm/year. The rainfall increases towards the east, with figures of up to 1,800 mm/year. In the north, the Amazon region (Pando) shows precipitation reaching 2,220 mm/year. The Chapare (Cochabamba) and the area bordering Maldonado (Perú) have the greatest precipitation in the nation, with values above 4,500 mm/year. On average, precipitation for all Bolivian basins has been estimated to be 1,419 mm/year, although the country's four macro-basins show important differences in this respect. The Amazon macro-basin receives 1,814 mm/year, while the Río de La Plata basin gets 854 mm/year. The Endorheic or Altiplano basin receives twice as much precipitation than the Río de la Plata, and four times more than the Altiplano. (Balance Hídrico de Bolivia, 1990). On the other hand, precipitation on the Pacific is minimal; from 1983-1995 its annual average was 59.1 mm (Urquidi, 2002a).

The annual flow of the main rivers shows significant variation depending on alterations of weather parameters. In addition, weather changes influence the level of evapo-transpiration; runoff and specific flow (FIGS. 4 to 6). The usefulness of the true annual evapotranspiration, shown in FIG. 3, is as an indicator of dryness in the various regions of the country. As could be expected, it almost coincides with FIG. 3 that shows normal precipitation. Thus, the Western Cordillera and the Bolivian Altiplano regions are the most arid, while the Eastern Plains, covered in lush vegetation, is the wettest and has the highest evapotranspiration values in the country. FIG. 5 shows the runoff coefficient, i.e. the rate between the rainfall in an area and the runoff. While the runoff is greatest in the plains of the



SOURCE: ATLAS AMENAZAS, VULNERABILIDADES Y RIEGOS DE BOLIVIA - 2008

FIG. 5. Runoff Coefficient



SOURCE: ATLAS AMENAZAS, VULNERABILIDADES Y RIEGOS DE BOLIVIA - 2008

FIG. 6. Specific Flow

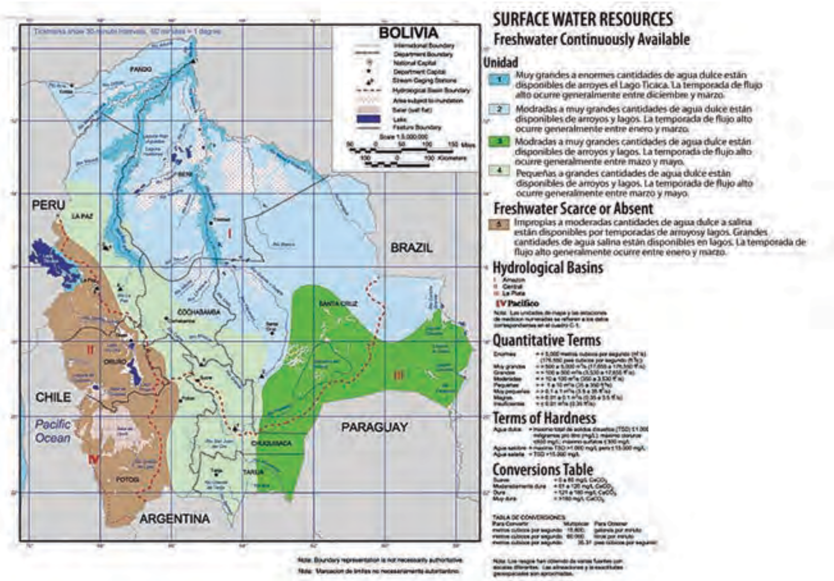


FIG . 7. Surface Water Resources

Amazon basin, it has a negative effect when annual floods are produced, adversely affecting productive activities and urban and road infrastructure. FIG. 6 compares specific runoff of the various basins in Bolivia. The contribution capacity of non-gauged sections of a specific basin or of others with similar areas; it can be assess from the statistical data of a gauged section. The map shows that areas with the greatest precipitation, west of the north and central Western Cordillera, Yungas and Chaparé regions, have the highest values (40 to 50 l/sec/km^{-2}). All of the Amazonian macro-basins vary between 10 and 20 l/sec/km^{-2} and 30 to 40 l/sec/km^{-2}; the Bermejo river basin has values of 10 to 20 l/sec/km^{-2}, while the basins in the remainder of the country have flows from 0 to 10 l/sec/km^{-2}.

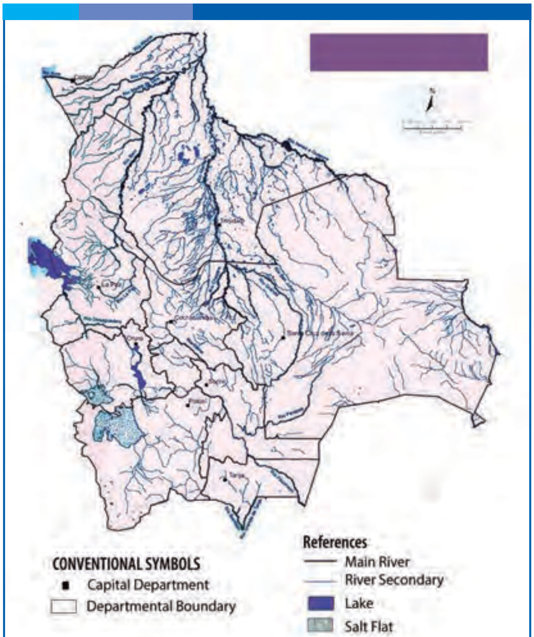
3. Availability of Surface Water

In Bolivian territory, surface waters run through a complex system of rivers, lakes, pools, wetlands and other bodies of water. The surface water resources of a specific region come from rainfall in its catchment basin, melted snow form snow capped mountains and springwaters (underground water discharge). Surface water basins in Bolivia, including the flow of certain rivers, were described in detail by Montes de Oca (2005).

FIGS. 7, 8 and Table 1 show the regional abundance of freshwater in Bolivian territory, which has been divided into two areas, one where freshwater is continuously available and another where freshwater is scarce or absent. On a national scale, the supply of water (blue water) is greater than 500,000 million cubic meters/year while the current demand is around 2,000 million cubic meters/year, which means less than 0.5% of the total supply. It is estimated that the national demand of water will increase 18% by the year 2012. This relative abundance

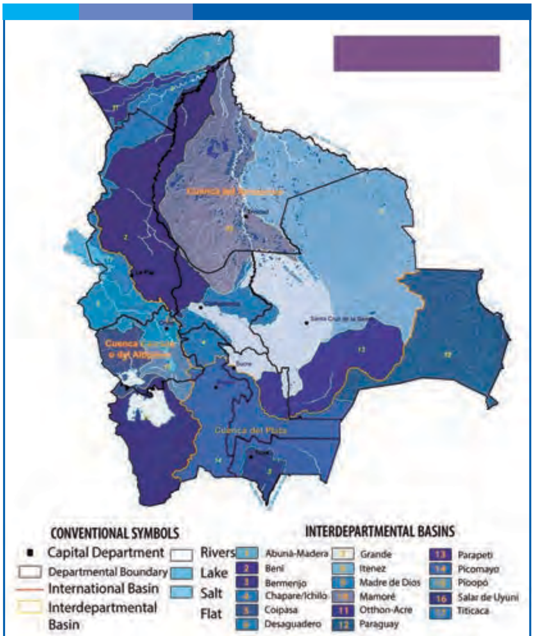
Table 1. Units of Available Fresh Water

Sector	Unit	Description
Continuously available freshwater	1	Various basins of the Amazon macro-basin, with large (>100 m^3/sec to 500 m^3/sec) to enormous (>5,000 m^3/sec) amounts of water. The high flow season generally occurs between December and March.
	2	Amazon macro-basin with moderate (>10 m^3/sec to 100 m^3/sec) to very large (>500 a 5,000 m^3/sec) quantities of water. The high flow season generally occurs between January and March.
	3	South of the Amazon macro-basin and downriver from the Río de la Plata macro-basin, with moderate (>10 m^3/sec to 100 m^3/sec) to very large (>500 to 5,000 m^3/sec) amounts of water. The high flow season generally occurs between March and May.
	4	The headwater basins of the Amazon and Río de la Plata with small (>1 m^3/sec to 10 m^3/sec) to very large (>100 to 500 m^3/sec) amounts of water. The high flow season generally occurs between March and May.
Freshwater scarce or absent	5	The entire macro-basin of the Altiplano with moderate (>10 m^3/sec to 100 m^3/sec) to very large (>500 to 5,000 m^3/sec) amounts of water. Great amounts of salt water available. The high flow season generally occurs between January and March.



SOURCE: ATLAS AMENAZAS, VULNERABILIDADES Y RIEGOS DE BOLIVIA - 2008

FIG. 8. Hydrographic Map



SOURCE: ATLAS AMENAZAS, VULNERABILIDADES Y RIEGOS DE BOLIVIA - 2008

FIG. 9. Hydrographic Basins

of water is a great advantage Bolivia has over its neighboring countries. However, as previously mentioned, there is a high spatial and temporal variability in weather conditions, and these include frequent extreme hydro-meteorological events such as rainstorms, droughts, hailstorms, snowfalls, frosts, etc. Likewise, the largest human settlements and human productive activities are concentrated in regions with the lowest rainfall in the country.

This, paradoxically, produces chronic water scarcity in several areas, which is aggravated by a lack of infrastructure for pluriannual regulation. The headwater basins of the four macro-basins of the country are in the western or Andean area (38% of the national territory), where it rains less, and where close to 70% of the population lives.

Bolivia has inventoried 260 wetlands, of which eight are Ramsar sites. The matter must be confronted in the near future with priority and in an orderly way. Close to 20% of the national territory is under ecological protection, either by the Sistema Nacional de Áreas Protegidas (National System for Protected Areas) or by ecological services contemplated in the Forest Law.

3.1 Hydrographic Basins in Bolivia

Hydrographic basins are considered to be the most adequate units for the management of hydrological resources. Dividing the country into macro-basins (large basins), basins, sub-basins and micro-basins is a step forward towards a more rational regulation of water. In 2007, the Minister of Water proposed a Plan Nacional de Cuencas (National Plan for Basins) to achieve "the cross-cultural development of basins as places for life and innovation in hydrological governability" (Plan Nacional de Cuencas, 2007).

Roche et al. (1992) were the first to suggest dividing the country into the three great hydrographic basins, as adopted by the Instituto Geográfico Militar (IGM) in 1998. The MAGDR-PRONAR (2001) also proposed a division into three great basins (Amazon, De la Plata and Endorheic), 10 basins and 36 sub-basins. However, the present work proposes four great hydrographic basins: 1) the Amazon macro-basin (65.9% of the national territory), 2) the Rio de la Plata macro-basin (20.9%), 3) the Endorheic macro-basin of the Altiplano (11.4%) and 4) the Pacific Ocean macro-basin (1.8% of the territory). The proposal to include the Pacific Ocean macro-basin is based on the latest studies of the hydrological resources existent along the border between Bolivia and Chile. Table 2 and FIG. 9 show the four macro-basins or great basins, 12 basins and 53 sub-basins and minor basins.

All Bolivian macro-basins are transboundary, thus it is relevant to consider the shared nature of their water. In most cases, Bolivia is found in the higher areas or headwater basins while the neighboring countries are in the middle or low areas. Within this context, progress has been made in the processes related to a shared management of the hydrological resources, the most relevant example being the binational transboundary basin of Lake Titicaca, where the most "legal" progress has been made in this respect. The water of Lake Titicaca is under joint ownership regulation, that is, any action in the basin on behalf of

Bolivia or Peru must be consulted and agreed upon by both countries. Due to the uneven distribution of rainfall and considering the size of the recipient basins, of the four macro-basins that configure the country, the Amazon macro-basin has the greatest availability of surface water, while the Pacific Ocean macro-basin has the least. It is estimated that 180,000 million cubic m/year of water flow through the Amazon macro-basin, 22,000 million cubic m/year through the Plata macro-basin, and 1,650 million cubic m/year of water through the Endorheic macro-basin (Montes de Oca, 2005). It has been calculated that only about 10 to 12 million cubic m/year of water flow through the Pacific Ocean macro-basin. Table 3 presents individual hydrological balance of some of the country's hydrographic basins.

FIG. 9 shows that the Amazon macro-basin consists of four major basins: Madre de Dios, Beni, Mamoré and Iténez, all flowing to the Madeira River (Brazil) on the northeastern corner of the Bolivian-Brazilian boundary. A curious case is the Parapeti River, that flows to the Iténez River basin during the rainy period, and in the dry period, a large part of its waters evaporate or filter into the Paraguay River basin. The Río de la Plata macro-basin, that flow the southern part of the country, is formed by three major river basins: Paraguay, Bermejo and Pilcomayo. The country also has a large number of lakes. There are six major lakes with a surface area greater than 200 Sq. Kms: Titicaca, Poopó, Uru Uru, Coipasa, Rogagua and Rogaguado. The estimated water volume in Lake Titicaca is 8,966 x 10^{11} cubic m, with a significant rainfall on its basin, which varies greatly from year to year (Baldivieso, 2005). On the other hand, the hydrological balance of Lake Poopó depends on flows of the Desaguadero River, which in turn depends on the variations of the water level of Lake Titicaca. There are numerous high altitude lakes on the macro-basins of the Altiplano and De La Plata River, which are head basins. These lakes are supply by the melting of the no longer perennial snows, due to global warming, of the Andean snow cap peaks.

3.2 Quality and Uses of Hydrological Resources

The Bolivian national water supply is calculated to be more than 500,000 million cubic m/year and the current demand is estimated to be just 2,000 million cubic m/year. The greatest demand for water, 94% of the total, comes from agricultural irrigation grounds through open irrigation ditches or channels. Table 4 shows the total surface irrigated, the water sources and the number of irrigation systems per department.

Water for human consumption is in second place, with an estimated demand of 104.5 million cubic m/year. Most of the water used in urban areas is for domestic use and only five of the nine department capital cities have a permanent 24 hour drinking water service.

The city of Cochabamba faces the greatest problems with respect to water supply, followed by the cities of Potosi, Sucre and Cobija. Table 5 shows the type of source and the flow supplied in the nine capital cities of Bolivian departments. In spite of the obvious coverage increase in drinking water service in urban and rural sectors, 30% of the Bolivian population still lacks potable water.

Table 2. Bolivian Macro-Basins, Basins and Sub-Basins

Macro-Basins	Basins	Sub-Basins and Minor Basins *
Amazon (724,000 Km^2)	Acre (2,340 Km^2)	
	Abuna (25,136 Km^2)	Manú Madera
	Beni (169,946 Km^2)	Orthon Madre de Dios (*Manuripi / *Manurimi) Madidi Tuichi Kaka Boopi Biata Quiquibey Colorado
	Mamoré (261,315 Km^2)	Yata Rapulo Apere Isiboro Ibare Rio Grande (*Yapacani)
	Iténez (265,263 Km^2)	Itonomas Blanco (* San Martín) Paragua7 San Miguelito
De la Plata (229,500 Km^2)	Pilcomayo-Bermejo (100,300 Km^2)	Bermejo Tarija Pilcomayo Pilaya-Tumusla (*San Juan del Oro / * Cotagaita)
	Dead Rivers of Chaco (32,100 Km^2)	
	Alto Paraguay (97,100 Km^2)	Bahía Caceres Pantanal (Curiche Grande) Otuquis, Río Negro
Endorheic or Altiplano (125,733 Km^2)	Lakes (45,948 Km^2)	Titicaca Desaguadero Mauri Caracollo Marquez Poopó
	Salt lakes (79,785 Km^2)	Río Grande de Lípez Puca Mayu Lauca (* Turco) Barras
Pacific Ocean (19,348 Km^2)	North (4,890 Km^2)	Carangas – Todos Santos Pisiga Cancosa
	South (14,458 Km^2)	Salar de Empexa Salar de Laguáni Salar de Chiguana Cañapa Pastos Grandes Salar de Chalviri Laguna Verde Zapaleri Silala Springs (**)

Note: (**) Not an hydrographic sub-basin.

BOLIVIA

Table 3. Hydrological Balance of Some of Bolivia's Basins

Basin	Station	Area (sq. km)	Precipitation (mm)	Evapo-transpiration (mm)	Runoff (mm)	Infiltration (mm)
Amazon Macro-basin						
Parapeti	Bolivian Andes	7,500	920	600	320	-
Izozog	Plain	45,000	887	875	12	57
Parapeti + Izozog	Total	52,500	892	836	56	49
Alto Beni	Merger with Kaka river	31,240	1,385	741	644	-
Kaka	Merger with Alto Beni river	21,040	1,586	777	809	-
Beni	Merger with Madre de Dios river	122,380	1,805	1,092	713	-
Madre de Dios	Merger with Beni river	125,000	2,715	1,107	1607	-
Mamoré	Merger with Iténez river	222,070	1,685	1,060	625	-
Iténez	Merger with Mamoré river	303,280	1,512	1,227	285	-
Mamoré+ Iténez	Merger with Mamoré-Iténez river	525,350	1,585	1,156	429	-
Madera (Total)	Exit Bolivia	724,000	1,818	1,170	648	-
Endorheic Macro-basin of the Bolivian Altiplano						
Lake Titicaca	Lakeshore	48,590	653	470	183	-
Lake Poopó	Lakeshore	27,740	370	438	0	-
Salar Coipasa	Shore	30,170	298	298	0	-
Salar Uyuni	Shore	46,625	190	190	0	-
Desaguadero	Chuquiña	29,475	414	361	53	-
Total Altiplano	Closed	125,733	463	390	83	9
De La Plata Macro-basin						
Pilcomayo	Misión La Paz	98,300	506	439	67	-
Bermejo	Juntas de San Antonio	11,981	1,159	714	418	-
Alto Paraguay	Puerto Suarez	119,219	1,056	830	226	-
Total De La Plata		229,500	829	530	299	-
Pacific Ocean Macro-basin						
Silala Springs	Laguna Colorada	150	59	914	0	14
Total Pacific		19,348	94	630	0	-
NATIONAL TOTAL		**1,098,581**	**1,419**	**958**	**461**	**19**

Table 4. Irrigation Systems by Water Source Per Department

Department	Rivers		Run off		Wells		Reservoirs		Total
	Systems (no.)	Area (has.)	Systems (no.)	Area (has.)	Systems (no.)	Area (has.)	Systems (no.)	Area (has.)	Area (has.)
Chuquisaca	615	18,059	28	587			5	2, 522	21 ,168
Cochabamba	415	48 ,979	95	3, 310	469	13, 442	56	21 ,270	87 ,001
La Paz	661	23, 271	258	4 ,166	13	163	29	8, 393	35 ,993
Oruro	224	8, 513	84	722	4	107	5	4 ,697	14 ,039
Potosí	735	10, 840	208	4, 829	9	68	4	503	16 ,240
Santa Cruz	225	11, 099	3	25	1	380	3	3 ,735	15, 239
Tarija	523	33 ,771	26	230			1	2 ,350	36, 351
TOTAL	**3 ,428**	**154, 582**	**702**	**13, 869**	**496**	**14 ,160**	**103**	**43, 470**	**226, 031**

Table 5. Types of Source and Flow Supplied in the Capital Cities of Each Department

City	Company	Source	Flow–Q (Lt/Sec)
La Paz / El Alto	EPSAS S.A. - Empresa Pública Social de Agua y Saneamiento (Mixed venture Company)	8 surface sources in the Cordillera Real (Tuni, Condoriri, Huayna Potosí, Milluni, Choqueyapu, Incachaca, Ajan Khota, Hampaturi Bajo)	Between 2,011 and 4,525
Santa Cruz	SAGUAPAC (Cooperative) 9 small cooperatives	Sub-surface aquifers (Tilala) (30 wells)	347 – 2,067 722
Cochabamba	SEMAPA (Municipal company)	Surface sources (Escalerani, Wara Wara, Chungara, Hierbabuenani) Sub-surface aquifers	Between 191 and 404 462
Sucre	ELAPAS (Municipal company)	Surface sources (Cajamarca system which includes the rivers Cajamarca, Safiri and Punilla) Surface sources (Ravelo system which includes the rivers Ravelo, Peras Mayum Jalaqueri, Murillo and Fisculco)	82 389
Oruro	SELA -Servicio Local de Acueductos y Alcantarillado (Local Waterworks and Sewage Services) (Municipal company)	Surface sources (rivers Sepulturas and Huayña Porto) Sub-surface sources (Wells in Challa Pampa, Challa Pampita and Aeropuerto)	34 528
Potosí	AAPOS (Municipal company)	Surface sources (Khari Khari lagoons)	195
Trinidad	COATRI (Cooperative)	Sub-surface sources	118
Tarija	Cooperative	Surface sources (Rivers: Rincón La Victoria, Guadalquivir, San Jacinto) Sub-surface sources	574 279
Cobija	Municipal company	Surface source (Bahía Stream)	24

In rural areas, there are too many difficulties with respect to the supply of drinking water, especially due to scattered population, reduced municipal ability and financing to generate and channel projects.

There is no interest from the private sector to invest in such projects. Apart from a low coverage, in most of the rural areas supply is achieved through community sources and there are no home connections. The industrial and mining sectors are also important consumers of water, using 31.5 million cubic m/year, or 1% of the total national demand.

Non-consumptive water resources are found in the 8,000 kilometers of navigable rivers, most of which are found in the Amazonian basin and the Paraguay – Paraná waterway.

In the energy sector, there are a total of 68 hydropower plants, including small systems with an installed capacity of 0.006 MW, and others up to 72 MW. Current installed capacity in hydropower plants is 308.4 MW, which corresponds to 1.5% to 2.8% of the economically utilizable potential. At the start of the year 2000, the National Electrification Company (ENDE – Empresa Nacional de Electrificación) registered another 81 hydroelectric utilities, with a theoretical national hydroelectric potential equivalent to an installed capacity of 190,000 MW, an exploitable potential of 57,000 MW and a technically utilizable potential in the range of 11,000 MW to 20,000 MW.

Regarding water quality, mining, industrial and human activities in larger cities are the most important water courses contaminators. Contaminated downstream waters are used mainly in agricultural activities. The contaminant load is extremely large and the estimated amount of organic matter is greater than 100 mg/Lt. Mining generates acid mine drainage (AMD) containing heavy metals that are difficult to control in surface and sub-surface hydrological systems.

In the major water courses of the Amazon macro-basin, the deterioration of water quality is manifested by the high concentrations of sediment from laminar erosion processes and the mass movement from higher basins, as well as high concentrations of mercury used to exploit gold. The same situation is seen in the rivers of the Rio de la Plata macro-basin, where the predominant mining activity is the exploitation of tin, zinc and lead.

4. Availability of Underground Water in Bolivia

Underground water is not always considered in watershed management plans. This is odd and highly impractical, as the greatest percentage of potable water and water for irrigation in rural and urban areas is supplied from underground water aquifers. The availability of underground water depends on various factors, such as the nature or type of rocks of the aquifers flow, i.e. either sedimentary or highly fractured effusive magmatic rocks. It also depends on hydrodynamic circumstances and charge/recharge conditions. The quality of underground water is directly related to the volume of rainwater or snow melted water, as well as the type and mineral composition of the host rocks or host sediments, where water accumulates or is stored after natural percolation. Underground water must be considered due to several other reasons in the entire analysis of water management; including that, in many cases, underground water and surface water are interconnected. There are many areas where wetlands, alluvial fans or other areas with permeable soils recharge aquifers have to be studied. In the water heads of the macro-basin of the Río de la Plata, such infiltration seems to be very important (Roche et al. 1992). During the rainy periods, the river feeds the aquifer, while the aquifer discharges into the river during the dry season.

This phenomenon has been observed in the Paraguayan Chaco with the Yrenda-Toba-Tarijeño aquifer. In general, throughout the national territory, the surface discharge areas are becoming more and more scarce. Underground water levels are falling and recharging areas are suffering high levels of contamination. Andean small wetlands (bofedales) are underground water discharge areas that do not drain and form wet grasslands that are used as feed by wild llamas and vicuñas.

Nationally, underground water hydrological resources have not been fully quantified. There are very limited local studies and their technical information is not organized or systematized. In 1985, the Bolivian Geological Service (GEOBOL -Servicio Geológico de Bolivia) developed and published a hydrogeological map of Bolivia FIG. 10 and defined five regional hydrogeological provinces which are fundamentally different in their lithological and structural conformation.

The five great hydrogeological units and a description of the freshwater abundance in each one are shown in FIG. 10. Map of Underground Water Resources.

Table 6 contains a careful description of the available freshwater in the various regional districts and units, as shown in FIG. 10 of underground water resources. A detail is given of the different types of aquifers, along with their geological age and rock composition. It also shows the variation in depth of the aquifers found in the unit. It is calculated that the aquifers with the greatest potential are found in the hydrogeological provinces of the Amazon, Pantanal-Chaco Boreal and Northern Altiplano.

In a second group are the aquifers in highly cracked consolidated rocks of medium to high productivity and some with important quantities of underground water resources. This group includes highly fractured magmatic rocks (ignimbrites) of the Neogene - Quaternary. These types of aquifers are found in the Pacific Ocean macro-basin, although not widely distributed. The presence of surface springs is conditioned by two main factors, the degree of the ignimbrite welding and strong fracturing related to regional and local tectonic faults.

5. Issues related to Transboundary Surface Waters

The issues related to transboundary surface waters are complex. Bolivia is both an upstream and a downstream country and has important flows draining to neighbouring countries. The issue areas are presented in FIG. 11 and details are summarized in the following paragraphs.

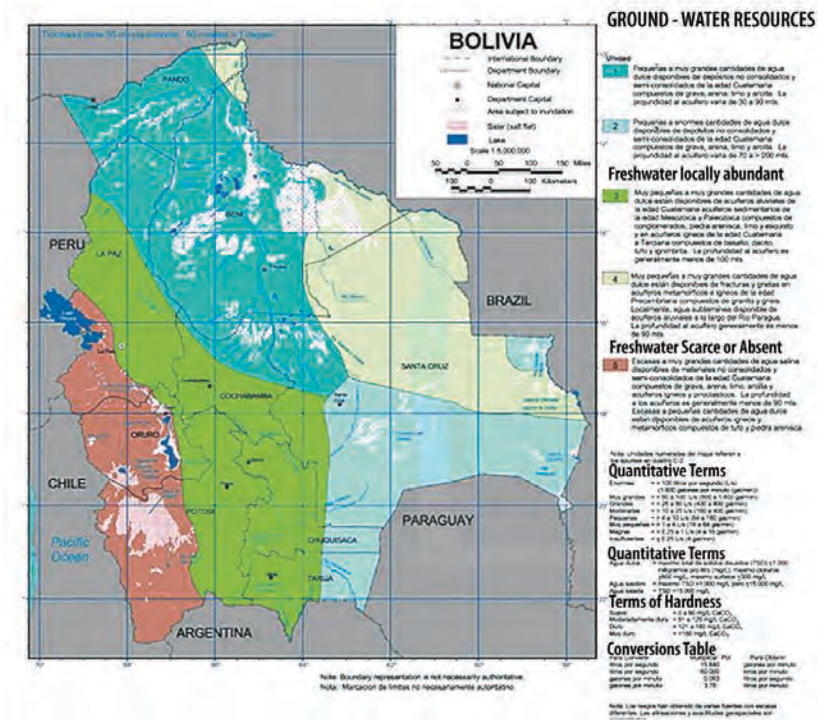


FIG. 10. Underground Water Resources

Table 6. Units of Underground Water

Sector	Unit	Description
Freshwater generally abundant	1	Small to very large amounts of freshwater available from non-consolidated or semi-consolidated deposits of the Quaternary period, made of gravel, sand, silt and clay. Aquifer depth varies from 30 to 90 m.
	2	Small to enormous amounts of freshwater in consolidated to semi-consolidated deposits of the Quaternary period, made of gravel, sand, silt and clay. Aquifer depth varies from 70 to 200 m.
Freshwater locally abundant	3	Very small to large amounts of freshwater are available in alluvial aquifers of the Quaternary period; sedimentary aquifers of the Mesozoic and Paleozoic eras, made of conglomerates, sandstone, silt and schists; and igneous aquifers from the Quaternary to Tertiary periods made of basalts, dacites tuffs and ignimbrites. Aquifer depth is generally below 100m.
	4	Very small to large amounts of freshwater available in fractures and crevices of metamorphic to igneous aquifers of the Precambrian era, made of granites and gneis. Locally, underground water available from alluvial aquifers along the Paraguay river. Aquifer depth is generally less than 90 m.
Freshwater scarce or lacking	5	Scarce to very large amounts of saltwater available from non-consolidated to semi-consolidated material of the Quaternary period, made of gravel, sand, silt, clay; and igneous and pyroclastic aquifers. Aquifer depth is generally less than 90m. Small to very large amounts of water are available in igneous and metamorphic aquifers made of tuffs and sandstone.

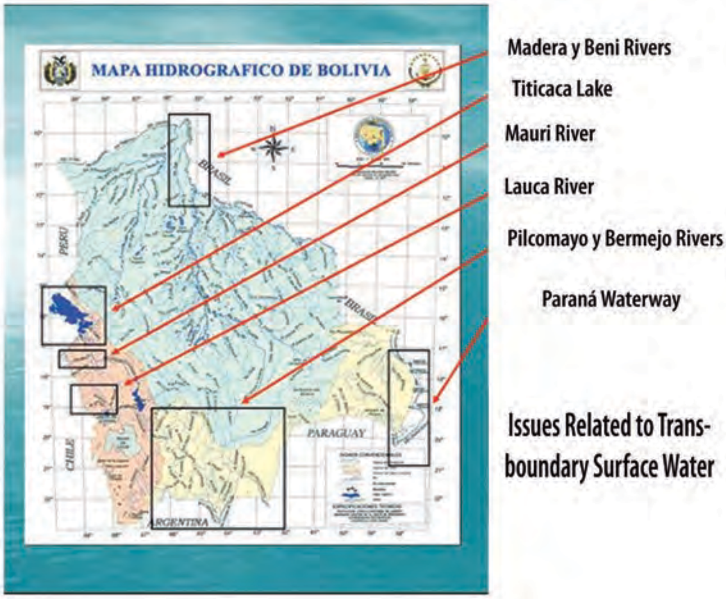


FIG .11. Issues Related to Transboundary Surface Water

5.1 The case of the Madera and Beni Rivers

The basin of the Madera River, an important river of the Amazon macro-basin, is the most important in the entire hydrographic system of the country. It covers an area of 720,057 Sq. Kms. representing 65.5% of the national territory and 99.7% of the surface covered by the Amazon macro-basin. It´s main flow is the result of large numerous river flows. The Madera River constitutes the vertebral column as a water way of the Bolivian northeast.

The Madera River is an international water course and an adjoining course that serves as a natural international boundary between the Brazil and Bolivia. In Bolivia, the Madera River originates where the Beni and Mamoré rivers converge. As it enters to Brazil, it changes its name to Madeira River and becomes the main affluent of the Amazon River. The Madera is not navigable along its 98 Km in Bolivia due to the many rock outcrops (Brazilian Shield) which are present in its riverbed and are called "cachuelas". Its affluents on the right bank within Brazilian territory are the Dos Araras and Ribera rivers, while on the left bank and in Bolivian territory they are the Mamoré, Abuná, Arroyo, La Gran Cruz and Beni rivers.

Almost all Amazonian rivers in the country provide an important source of transportation and the means of subsistence for riverside inhabitants. Some rivers like the Ichilo, Mamoré, Iténez, Beni and Madre de Dios, also sustain a commercial fishing rural industry. A total of 389 fish species have been identified in the Bolivian Amazonia.

During 2001 and 2002, with permission from the government of Brazil, the Brazilian companies Furnas Centrais Eléctricas SA and Constructora Noberto Odebrecht SA performed a study of the hydropower nergy potential of the Madera River in Bolivia and of the Madeira River, in order to determine the location of four hydropower electrical plants.

The feasability studies were completed in 2004 and 2005; the Leme Engenharia company presented an Environmental Impact Study (EIS). After questioning from various Brazilian environmental agencies and the Bolivian government, the EIS was approved in 2007 by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA -Instituto Brasilero del Medio Ambiente y Recursos Naturales Renovables). The license for the construction of the reservoir for the San Antonio hydropower plant on the Madeira river was granted by the Brazilian government in August of 2008.

Related Issues:

- The construction of four reservoirs is planned along the rivers Madeira, Madera and Beni to supply a similar number of hydropower plants and increase the water level to aid fluvial transportation. Two of the reservoirs will be built in Bolivia and two in the Brazilian side. Table 7 shows some of the characterisitcs of the plants to be built.
- These reservoirs will have a serious environmental and social impact due to the extensive flooding area estimated at more than 2.6×10^5 Sq. Kms.
- A devastating cutting of trees is programed in areas of the Amazon forest. The new area will be used for the expansion of soybean agriculture, with an estimated annual production of 24×10^6 TM of soy.
- Brazil would compensate the ecological damage and the use of water by financing the pavement of Corredor Vial Norte La Paz - Guayaramerín – Cobija (Northern Highway Corridor La Paz Guayaramerín – Cobija).
- Bolivia should have insisted on the importance of performing the analysis and technical discussion of the projects to be constructed in Bolivia and Brazil.
- A second issue is the current contamination by metallic mercury due to gold mining operations in the Madera River.

5.2 The Case of Lake Titicaca

Lake Titicaca is shared with the Republic of Peru and has an extension of 8,030 Sq. Kms. with its water surface at an average altitude of 3,809 m. The average depth in the Lago Grande (the larger part of the lake) is 135 m and in the Lago Pequeño (smaller part of the lake) is 23 m. The estimated water volume is $8{,}966.3 \times 10^{11}$ cubic m.

Fishing of trout and native species is an important activity in Lake Titicaca. In the Bolivian portion of the lake, the capture rate reaches a maximum of 2,600 tons per year. However, there is evidence of over-fishing of exotic species, and there is concern about the future of trout and the survival of certain native species. Fishing in Lake Titicaca supports about 1,500 and 3,500 full time, part time or occasional Bolivian fishermen.

Bolivia and Peru have signed the “Acuerdo del Lago Titicaca (ATL)” (Lake Titicaca Agreement) and a Bilateral Organitzation for Lake Titicaca has been formed. The Lake Titicaca Authority is appointed and authorized to regulate all activites in the lake. The Unidad Operativa Boliviana de la

Table 7. Projected Power Plants

Hydropower plant	Fall (m)	Installed Capacity (mw)	Annual Energy (gwh)
Santo Antonio	18	3,580	19,000
Jirau	20	3,800	20,000
Abuna – Guayaramerín	20	4,200	25,000
Esperanza	15	3,800.	20,000

Autoridad Binacional del Lago Titicaca (UOB-ALT) (Bolivian Operative Unit of the Binational Authority of Lake Titicaca) is the technical branch of this Bilateral Organization.

The activity of UOB-ALT is directed towards several technical activities: thematic cartography, including surveys; measurement of flow in the main river courses of the basin; conservation and management of natural resources; conclusion and updating of studies of the hydrographic basins of Lake Titicaca – Desaguadero River – Lake Poopó – Salar de Coipasa (TDPS). It also includes the execution of the Direction Plan for the construction of: a) irrigation bridges, b) hydraulic works, c) dredging of the Desaguadero River and d) building of gates to control over flooding.

Related Issues:

- The basin of Lake Titicaca is shared by Peru and Bolivia.
- It is necessary to solve the issue of flooding and water regulation.
- The total fluvial contribution of 66.7 x 10^9 cubic m is being questioned by Peru, as more than 80% of the water reaching the lake comes from Peruvian rivers.
- It has been estimated that the water drained through the Desaguadero River is 0.66 x 10^9 cubic m, all going to Bolivian territory.
- Current pollution of lake water by untreated sewage spilled in by the town settlements on the shores (Puno, Copacabana and others) is of great concern. This environmental issue must be addressed by both countries.

5.3 The cased of the Mauri (Maure) River

The water head of the Maure River is at the Laguna Vilacota in the Peruvian Cordillera Occidental, it fows through a large portion of Peruvian territory and then flows into Bolivia at a site near the town of Charaña (Urquidi, 2005b). It forms part of the TDPS (Titicaca, Desaguadero, Poopó, Salares) system which drains the water of the central Bolivian Altiplano. The hydrological basin of the Maure-Mauri River covers part of the departments of Puno and Tacna (Perú), La Paz and Oruro (Bolivia) and of the Parinacota de la Región I province (Chile).
In order to deal with the problems related to the Mauri (Maure) river, Bolivia and Peru

formed the Binational Comision for the Mauri River (Comisión Binacional del Río Mauri) with operating bases in La Paz and Tacna. The Comision is considered part of the Lake Titicaca Agreement (Acuerdo del Lago Titicaca ALT).

Related Issues:

- Addressing issues of natural boron and arsenic contamination caused by the upwelling of springwater in the Quebrada Putina in Peru (Table 8 and FIG. 12).
- A request from Peru to reduce the total flow of the Maure river to Bolivia, by cutting the flow of fresh water of the Maure rivers affluents.
- Building of channels on the Peruvian side to avoid pollution of the rivers flowing into the Maure River. A "by pass" system will chanel the water into channels constructed in Peru.
- Economic compensation from Peru to Bolivia, and possibly from Bolivia, for the use of Lake Titicaca's water through the Desaguadero River.

5.4 The Cased of the Lauca River

The Lauca River water head is located in the Ciénagas de Parinacota and the Laguna Cotacotani (4,400 m) of Chile, and flows into the Laguna de Coipasa, close to the town of Santa Ana de Chipaya in Bolivia (3,760 m). It crosses the Bolivia-Chile border at Portezuela de Macaya (3,892 m) at Hito XX (Urquidi, 2005a). Since the 1930´s, the government of Chile considers the Lauca River as a successive international river (transboundary) and claimed the right to use 50% of its flow.

In 1962, the unilateral alteration by Chilean authorities of the river course and the transfer of 50% of its water flow towards the Azapa Valley in Arica (Chile), without any compensation to Bolivia, caused the rupture of diplomatic relations with Chile by Bolivia.

Table 8 Toxic Elements and Adequateness of Water from the Maure-Mauri River

Site	B (mg/l)	As (mg/l)	Population Use	Irrigation Use
Kovire	1.43	< 0.10	Acceptable	C1S1
Calachaca	30.5	5.63	No	C3S3
Frontera	12.5	2.0	No	C3S2
Abaroa	13.5	1.81	No	C3S2
Calacoto	10	0.69	No	C351
Caquena 1	8.82	0.13	No	C351
Caquena 2	16	0.5	No	C4S3
Blanco			No	C2S1
M. Calachaca			No	C2S1
M. Mamuta			Acceptable	C1S1

The increase in "Calachaca Site" is due to "La Quebrada Putina" polluted waters.

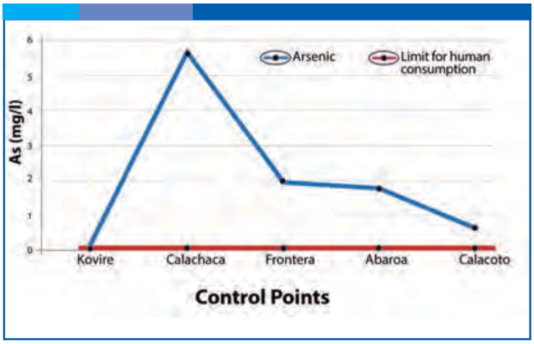


FIG. 12. Variation of Arsenic Levels in the River Maure – Mauri

The average flows in Bolivian territory are the following:

- Lauca River(border): 2.60 cubic m/sec.

- Sajama River: 4.99 cubic m/sec.
- Cosapa River: 3.00 cubic m/sec.
- Turco River: 2.45 cubic m/sec.
- Laguna Coipasa: 13.00 a 15.00 cubic m/sec.

Related Issues:

- Bolivia considers that must have the real figures of the water flow of the Lauca River in Chilean territory, to ensure it receives the 50% it is entitled to. There is no information about the flow at the source and at the end of the water transfer channel towards the Azapa Valley.
- Bolivia expects some sort of compensation for the water tranfered to the Azapa Valley.
- The reestablishment of diplomatic relations between both countries.

5.5 The Case of the Pilcomayo and Bermejo Rivers

The Pilcomayo basin is trinational (Bolivia - Argentina - Paraguay) with a population of 1.5 million, of which 1.0 million live in Bolivia. The Bermejo basin is binational (Bolivia - Argentina) with a popultation of 1.12 million, of which 243,000 are Bolivian citizens.

The Rio de la Plata macro-basin is located in the southeast corner of the country. It has a surface of approximately 224,918 Sq. Km. and is the second largest in Bolivia. This basin is shared by the departments of Tarija, Santa Cruz, Chuquisaca, Potosí and Oruro.

In order to manage the basins of the Pilcomayo and Bermejo rivers, the following organizations have been formed through agreements signed by Bolivia, Paraguay and Argentina:

- Comité Interamericano de la Cuenca del Plata (Interamerican Committee for the Plata Basin).
- The "Comisión Nacional de los Ríos Pilcomayo y Bermejo" (National Comission for the Rivers Pilcomayo and Bermejo) was created in 1989 to coordinate and agree on policies and actions for international negotiation of both basins. This collegiate body has an "Oficina Técnica Nacional (OTNPB)" (National Technical Office) with headquarters in Tarija and is in charge of operations and technical contributions.
- In 1995, the "Comisiones Trinacional y Binacional" (Trinational and Binational Comissions) were created for each of the basins.
- The OTNPB has the following programs:
  * Strategic Action Plan for the Binational Basin of the Bermejo River.
  * Construction Program for the Las Pavas, Arrazayal and Cambarí Reservoirs.
  * Project for Comprehensive Management and Master Plan of the Pilcomayo River Basin.

Related Issues:

- Bolivia is the water head of the Basin.
- Maximize the use of its water in Bolivia (regulated flow).
- Avoid causing critical damage to down stream countries.
- Reservoir Projects (funding and uses).
- Continue the projects for environmental recovery and the disposal of sediments.

5.6 The Case of the Paraguay – Paraná Waterway

Aguirre and Graveral ports are part of the Paraguay – Paraná Waterway and they receive both, national and internatinal freighters. This waterway is important since it allows Bolivia access to the Atlantic Ocean. It has a length of 3,442 Km from its headwaters in the state of Mato Grosso, to the delta of the Paraná River. The surface area is approximately 1,750,000 Sq. Kms, with a population large than 17,000,000. In Bolivia, the area of influence reaches 370,000 Sq. Kms (Santa Cruz, Tarija and Chuquisaca). Currently, the waterway has a great importance for the trade of soy and iron minerals. It is regulated by the following organizations and agreements:

- Comité Intergubernamental de la Hidrovia Paraguay - Paraná (CIH) (Intergovernmental Committee for the Paraguay-Paraná Waterway).
- Plata Basin Treaty.
- Acuerdo de Transporte Fluvial por la Hidrovia Paraguay - Paraná (Puerto Cáceres-Puerto de Nueva Palmira) (Agreement for River Transport on the Paragua – Paraná Waterway).
- Seven additional protocols and regulations were signed on: a) navigation and security, b) insurance, c) equal opportunity conditions to allow greater competitiveness, d) customs issues, e) temporary suspension of flag, and f) solution of controversies. The seventh protocol is a 15-year deferral of the Agreement.

Related Issues:

- There are limitations as to the number of barges that can be transported to Bolivian ports (Central Aguirre and Gravetal), due to Brazilian infrastructure near the channel.
- Convoys smaller than 2 x 2 (2,500 to 3,000 MT) navigate the stretch Cáceres - Corumbá.
- Convoys of four barges with tugboats at the stern and bow navigate the Corumbá - Tamengo Channel.
- Radial curvatures that are too limited.
- National Ports Central Aguirre and Gravetal

6. Issues related to Trasboundary Underground Water

Underground water should be considered in the comprehensive analysis of any water management. In many cases, surface and underground waters are interconnected. The main areas for aquifer recharges are wetlands (moors), alluvial fans or other areas with permeable soils. In times of heavy rains, the river feeds the aquifer, while the aquifer discharges to the river in the dry seasons. The areas for surface discharge are currently more scarce, due to a drop in water tables and high contamination on the recharging areas. Underground water resources have to be quantified. Small and very limited local studies exist with systemized technical information of wells drilled in the Valle Alto de Cochabamba and North Altiplano. In 1985, the Bolivian Geological Service (GEOBOL) developed and published the Hydrogeological Map of Bolivia.

Currently, departmental authorities have various internationally funded programs for well drilling in order to provide water to rural populations. However these institutions are not registering information on the wells and their hydrogeological characteristics. This information will be lost and will be unavailable in the future to locate, qualify and quantify the numerous sub-surface basins within the national territory. The issues related to Trasboundary Underground Water are more complicated than those about surface waters. The FIG.13 shows the main issues.

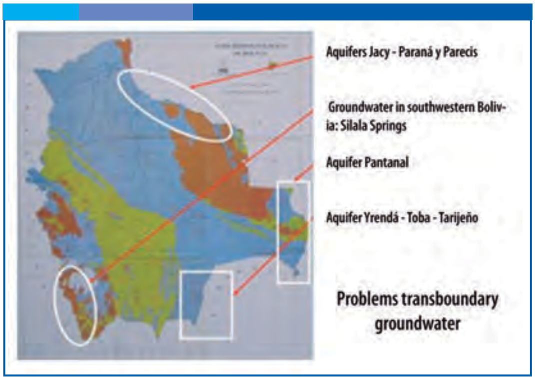


FIG. 13. The issues Related to Trasboundary Underground Water.

6.1 The Case of Underground Water in the Bolivian Southwest: Silala Springs

The surface water outcropping as springs, in the Silala area, comes from a transboundary aquifer located on the border between Bolivia and Chile. It has a hydrological gradient that determines a water movement form east to west, which means from Bolivia to Chile.

The Silala transboundary aquifer is hosted in the Silala Ignimbrites (7.8 ± 0.3 Ma, Upper Miocene) and probably in infrayacent geological formations that do not outcrop in the area. The Silala Ignimbrites are highly fractured and outcrop due to differential erosion of the volcanic rocks and faults that give rise to the formation of gorges widened by fluvioglacial processes. Because of the relatively low degree of welding and high fracturing of the ignimbrite, they allow high transmissivity and permeability of the Silala aquifer. All springs that occurre in the Silala area, as much as in the Bolivian as in the Chilean side, are discharges from the Silala Ignimbrites aquifer. In many cases, the springs emerge directly from joints and fissures in the ignimbrite (mostly on the Chilean side). The saturated Andean marshes (bofedales) in the area (mostly on the Bolivian side), are formed over fine Recent sediments, that cover the ignimbrites, with water from the underlying ignimbritic aquifer.

The Departmental authorities of Potosí granted the use of the Silala waters to the Antofagasta (Chili) and Bolivian Railway Company Limited by means of the Pubic Document No. 48 of September 23rd, 1908. Since then, two Chilean compañies have made use of these waters. The waters were granted for its use in steam locomotives of the railway company. Since the 1960s, these locomotives were replaced by diesel engine locomotives that are much more efficient. From then on, these waters were used to satisfy the water demand of the cities of Antofagasta, Calama and others, in addition to the demands of the Chilean copper industry of CODELCO.

In 1908, the springs forming the Andean marshes were channeled through open collector channels made of stone built by personnel of the railway company. If the marshes were not disturbed, the water would have remained standstill and evaporate rapidly. Currently, the surface water only drains towards Chile in these open collectors. The surface water flows only through the man-made open channels.

On the other hand, Chile considers the water draining from the Silala springs in the Bolivian side as a continuous natural course of an international transboundary river. Both positions have been expressed in diplomatic documents processed in 1999, which remain unchanged to the present date.

According to C^{14} studies performed by the Bolivian Geological Survey towards the end of 2006, the Silala fresh waters are ancient (not fossil water), with an age of 9,300 to 10,000 years old.

The hydrogeochemical and physical characteristics of the water flowing from the Silala Springs, both in the Anden Marshes and in the ignimbrite walls, is a sodium bicarbonate water. From a geochemical viewpoint, a relationship was found between cations of rNa > rCa > rMg and the anions $rHCO_3$ > rCl > rSO_4.

The RAS was determined to be class C1S1, or low salinity and low relation to Na. The TDS values are between 111mg/Lt and 192 mg/Lt, while the pH is between 7.40 and 8.35.

The electrical conductivity reveals two types of water, one with values from 209 to 240 µs/cm found in the southern moor (bofedal), and another with values from 95 a 120 µs/cm on the northern marsh, which coincides with water from the springs on main gorge of the Chilean side. The temperature of springwater is 13°C to 16°C.

The flow on either side of the border is the following:

Bolivian side
- Average flow: 200 liters/sec
- Piexometric level: 0.40 a 0.67 m
- Number of springs: more than 70

Chilean side
- Average flow: 300 liters/sec
- Number of springs: more than 30

Related Issues:
- The Silala aquifer is aconfined one without or very little recharge. These transboundary underground water system has to be ecologically preserved with its current 500 Liters/Sec average flow.
- Bolivia considers that in the past 100 years, Chile has received free surface water from the Silala springs that outcrop on the

FIG. 14. Springs, Silala.

Bolivian side that do not originate a natural river flow.

• Since 1997, the government of Chile offered to buy 50% of the water produced on the Bolivian side, that is 100 Lt/sec, at a price still to be determined. This offer has been recently repeated by the Chilean government according to publications in national media and is under consideration by the Government of President Evo Morales.

6.2 The Case of the Yrenda - Toba – Tarijeño Aquifer

The aquifer called Yrendá - Toba - Tarijeño by Paraguay, Argentina and Bolivia, has an approximate surface of 300,000 Sq. Kms and is found within multi-layered non-consolidated sediments of Quaternary and Tertiary age. It is not a confined aquifer, instead it is an aquifer system with many permeable layers with variable amounts of water.

The Bolivian part of the aquifer includes an area corresponding to the Tarijean, Chuquisaca, and Sante Cruz del Sierra Chaco. To the west is the Subandean Aguaragüe mountainous region, while the eastern limit is yet to be defined, but is approximately in the area of Mariscal Estigarribia, in the Paraguayan Central Chaco. The northern and southern limits are also undefined (Pasig, 2005).

The Binational Commission for the Management of the Yrendá – Toba – Tarijeño Aquifer System (Comisión Binacional en la Gestión del Sistema Acuífero Yrendá - Toba – Tarijeño) was created to study and collect technical information.

Related Issues:

- A multi-layer aquifer has been over-exploited by users in Paraguay.
- Paraguay questions the use of water in the recharge areas (Serranías de Aguaragüe).
- The hydrogeological potential of the aquifer is still not well known.
- There is an urgent need for a sustainable use of the aquifer.

6.3 The Case of the Jacy - Paraná and Parecis Aquifers

Bolivia lacks the technical information related to these transboundary aquifers and that are in the altered basement rocks of the Central Shield (Archean Age), along the northwestern border between Bolivia and Brazil. In addition, its western boundaries in Bolivia have not been determined.

Related Issues:

- There is little information on both sides of the border (Bolivia and Brazil) and the degree to which the aquifer is "transboundary" is unknown.
- The areas for charge and discharge in Bolivia are unknown.
- The hydrogeological potential of the aquifers is unknown.
- The area has a high hydroelectric potential.
- Water is used intensively for agricultural irrigation on the Brazilian side.
- There is a need to consider the sustainable use of water in both aquifers.

6.4 The case of the Pantanal Aquifer

This Cenozoic transboundary aquifer is located on the southeastern border of Bolivia with Brazil. From an ecological, economic and social point of view, it is one of the most important continental systems. In the State of Rondonia, Brazil, it extends beyond 160,000 Sq. Kms, however its surface to the west as it enters Bolivia, is still to be established. It forms extensive "curiches" (swamps formed by flooding) and flooded areas with a length greater than 150 Km parallel to the international border. Technical information on the aquifer is completely lacking in the Bolivian sources.

Related Issues:

- Information on the aquifer is very scarce, almost non existence, on the Bolivian side.
- The discharge areas are unknown in Bolvian territory.
- The water surface level on the Brazilian side varies from 6 to 8 meters.
- It is lacated within an important ecological region: El Pantanal.
- The border is a source of conflict from the agricultural point of view, especially on the Brazilian side.
- It is an area with an important future in mining, especially of iron minerals, corresponding to the Mutun in Bolivia and the Urucum in Brazil.

7. References

1. Baldivieso Manrique, G. (2005). Bolivia es una Potencia Hídrica Amenazada por la Desertificación. La Razón. La Paz, Bolivia.
2. Constitución Política del Estado. Promulgada el 7 de Febrero de 2009. Impresión Oficial, Gaceta Oficial.
3. INE (2001) Encuesta de Hogares - 1999. La Paz, Bolivia. 235 p.
4. Liebers Baldivieso, A. (2002) Agua: de elemento de conflicto a fuente de integración (El caso boliviano). La Paz, Bolivia. 38 p.
5. MAGDR-PRONAR (2001) Mapa de Ordenamiento Hidroecológico de Bolivia, Correlación con niveles de pobreza y degradación de recursos naturales renovables. La Paz, Bolivia.
6. Mattos, R. Y Crespo, A. (2000) Informe nacional sobre la gestión del agua en Bolivia.
7. Maurice-Bourgoin, L. (2001) El mercurio en la Amazonía Boliviana. La Paz, Bolivia. 75 p.
8. MDSP-JICA (1999) Estudio de evaluación del impacto ambiental del sector minero, en el departamento de Potosí. Mitsui Mineral Development Engineering Co., Ltd., Unico International Corporation.
9. MDSP (2001) Estrategia nacional de biodiversidad. 193 p.
10. Montes de Oca P., I. (2005). Geografía y Recursos Naturales de Bolivia. Editorial Offset Boliviana Ltda. La Paz, Bolivia.
11. Pasig, R. (2005). Aguas Subterráneas en el Sudeste de Bolivia. Política Exterior en Materia de Recursos Hídricos. UDAPEX (Ministerio de Relaciones Exteriores y Culto)-PNUD. EDOBOL. La Paz, Bolivia.
12. Quiroga B., R., Salamanca, L. A., Espinosa, J. C., Torrico, G. (2008). Atlas Amenazas, Vulnerabilidad y Riesgos de Bolivia. Plural Editorial. La Paz, Bolivia.
13. Rebouças, A. da C. 2006. Águas Subterrâneas. Águas Doces no Brasil. Escrituras. 3ra. Edic. São Paulo, Brasil.
14. Roche, M. A. et al. (1992). Balance Hídrico Superficial. Publicación PHICAB. La Paz, Bolivia.

15. Urquidi Barrau, F. (2005a). Recursos hídricos en la frontera boliviano-chilena (Silala y Lauca). Política Exterior en Materia de Recursos Hídricos. UDAPEX (Ministerio de Relaciones Exteriores y Culto)-PNUD. EDOBOL. La Paz, Bolivia.
16. Urquidi Barrau, F. (2005b). Recursos hídricos en la frontera boliviano-peruana (Mauri). Política Exterior en Materia de Recursos Hídricos. UDAPEX (Ministerio de Relaciones Exteriores y Culto)-PNUD. EDOBOL. La Paz, Bolivia.

Boats over the sea in Buzios,Rio de Janeiro, Brazil

Water Policy in Brazil

José Galizia Tundisi[1], Marcos Cortesão Barnsley Scheuenstuhl[2]

[1]Instituto Internacional de Ecología, São Carlos, Brasil
[1]Instituto Nacional de Ciencia y Tecnología en Recursos Minerales, Agua y Biodiversidad (Ministerio de Ciencia y Tecnología)
[1]Feevale University, RS

[2]Academia Brasileña de Ciencias

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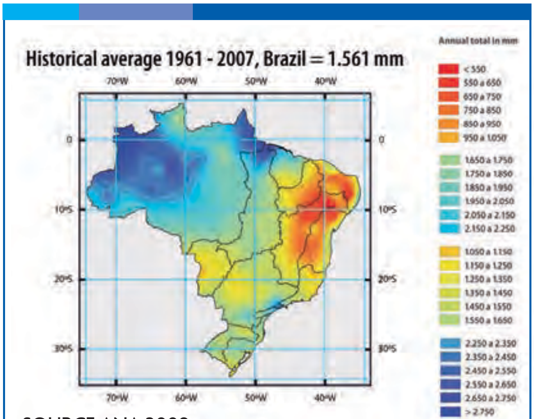
1. Introduction

In this document the authors describe the distribution, the availability and the contamination of the water resources in Brazil as well as the water policy needed to cope with these problems. The institutional organization of the integrated management of water in Brazil is presented, and challenges to further develop a water policy in Brazil are discussed. These challenges range from, a better enforcement of a legal framework at watershed level, to reduce contamination and disasters which occur due to hydrological changes and watershed degradation, to the development of technologies for an adequate ecological management of water resources with regards to watershed protection, restoration, prevention and deterioration. Investments in Science, Innovation and Technology dedicated to water resources need a vigorous and long term strategy in order to sustain a permanent improvement on the water policy. Regions which require a special attention with regards to the water policy in Brazil are the Amazon and the Northeast.

2. Water Resources in Brazil

Brazil has 12% of the Planet Earth's fresh water resources. These resources are unevenly distributed throughout its national territory, which extends from 5° north latitude to 34° south latitude, with a variety of climates and climatological influences which range from the Equatorial region, to the cold fronts originating in the Antarctic Zone. The average precipitation in Brazil (historical data 1961-2007) is of 1,765 mm, ranging from 500 mm in the semiarid regions of Northeast Brazil to 3,000 mm in the Amazon region (FIG. 1). The main watersheds of Brazil are represented by 12 hydrographic regions. The three most significant ones are: the Amazon Watershed, The Paraná Watershed and the São Francisco River Watershed (FIG. 2).

In FIG. 3 we see the spatial distribution of specific water discharge which ranges from less than 2 liter/second/km^2 (in semiarid region of the Northeast) to more than 30 liters/second/km^2. Currently, fluviometric stations all over Brazil are providing representative data showing specific discharge at all twelve watersheds. The distribution of ground waters in Brazil is also inconsistent. There are regions with abundant water availability (such as The Guarani Aquifer in southern Brazil and other sedimentary aquifers) and regions with low availability (such as those of the crystalline rocks in the semiarid regions). The sedimentary aquifers occupy 48% of Brazil´s total area. FIG. 4 shows the area of recharge of aquifers in relation to the twelve hydrographic basins. The number of new wells constructed for exploitation of ground water is around 10.500/year in Brazil, which shows the economic importance of this resource.



SOURCE ANA 2009

FIG. 1. Average Precipitation in Brazil

(SOURCE ANA 2009)

FIG. 2. The Twelve Hydrographic Watersheds of Brazil

3. Water Uses

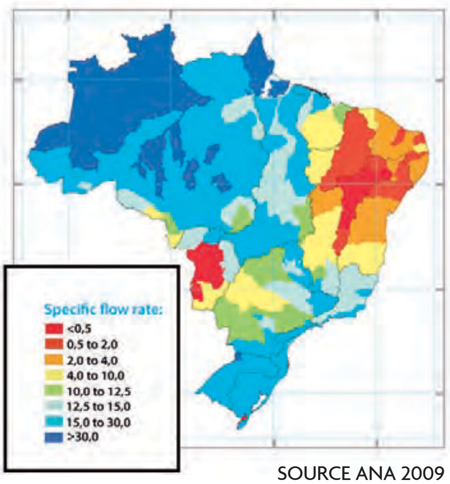
As in many other countries or regions of the world the forms of utilization of water in Brazil are diversified and their intensity is related to the economic, social and agricultural development in the 12 watersheds. Among the consumptive uses are: public supply (urban and rural), industry and irrigation. As for non consumptive uses, we can cite: hydroelectricity, fisheries, navigation, agriculture, tourism and recreation) (FIG. 5). An important issue in Brazil is the discharge of used water into reservoirs, rivers and lakes. When this water is not treated (as is frequently the case) it becomes a problem that needs to be seriously considered, seeing that the water becomes unavailable to support any other activity which depends on clean water. Hydroelectricity generates 68% of the total energy produced in Brazil (Agência Nacional de Energia Eléctrica, inf. 2008). The potential of hydroelectricity in the southeast of Brazil is now almost worn out, therefore a large percentage of them potential of hydropower still remains in the Amazon region (70% of all hydroelectricity potential of Brazil). This is an issue which needs to be considered for the future water policy in Brazil (Tundisi & Matsumura-Tundisi, 2010a; Tundisi and Campagnoli, in preparation).

4. Multiple Water Uses and Conflicts

The multiple uses of water in Brazil, together with the economic development of the country, have generated conflicts in the following areas:

1. Water use in agriculture and the supply of water for urban areas;
2. The public supply of water has been affected due to an increase of agribusiness production and deforestation, which have affected areas of recharge of aquifers, and water quality at their sources.
3. Expansion of urban non treated solid waste disposal and the water quality of surface and ground water.

4. Expansion of hydroelectricity impact in the tributaries of the Amazon River and disruption of the hydrosocial cycle.
5. Heavy contamination by toxic metals, eutrophication, excessive use of fertilizers in agriculture, discharge of non-treated domestic water and costs of water treatment.



SOURCE ANA 2009

FIG. 3. Spatial Distribution of Specific Discharge in Brazil

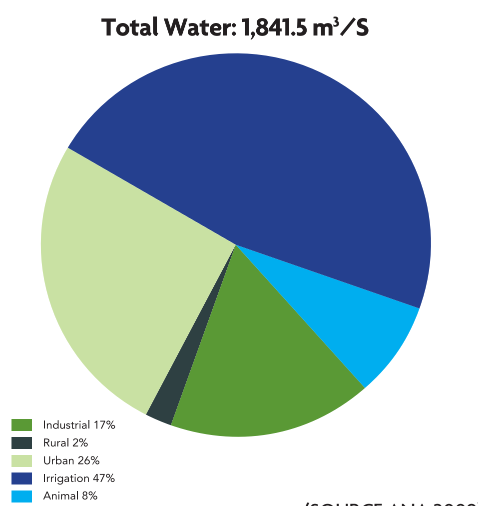
FIG. 4. Recharge Area of the Main Aquifers in Brazil

6. Increase in the cost of treatment of water due to the degradation of the sources, deforestation, and contamination of aquifers.
7. Impacts of degraded water on human health, mainly in urban and metropolitan regions.

5. The Water Quality in Brazil

The present situation of water quality in Brazil is a consequence of several impacts which resulted from the following situations

1. Urbanization and discharge of non-treated waste water in rivers, lakes and reservoirs (UNESCO, UNEP, 2008).
2. Inadequate disposal of solid waste, which impacts the surface and the ground waters.
3. Agricultural activities with excessive use of fertilizers, pesticides and herbicides.
4. Industrial activities with effluents containing toxic metals; deforestation and the increase of transportation of suspended material reducing the volume of the reservoirs, changing morphometry of the rivers and the natural lakes; mining activities degrading the surface and ground waters; production



(SOURCE ANA 2009)

FIG. 5. Uses of Water in Brazil

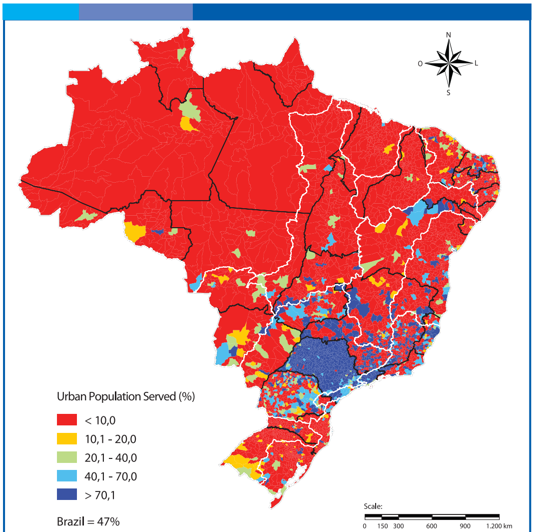
of hydroelectricity and construction of reservoirs which change river flows, river biodiversity and are the cause of several impacts on major watersheds such as the Paraná, São Francisco and the Amazon River tributaries (Straskraba & Tundisi, 2008; Tundisi & Matsumura-Tundisi, T, 2008).

As a consequence of the several economic activities and the multiple uses of water, the main problems of water pollution and contamination are the increase of toxicity of the surface and ground waters; the eutrophication of rivers and reservoirs with excessive growth of toxic cyanobacteria causing organic contamination of water sources, especially near the large urban centers and metropolitan regions; siltation, and emission of greenhouse gases from eutrophic waters. (Azevedo, 2005; Jorgensen et al., 2005; Tucci & Mendes, 2006; Straskaba and Tundisi, 2008; Tundisi et al., 2006; Abe et al., 2009; Sidagis Galli, et al., 2009; ANA. 2009; Bicudo, Tundisi and Cortesão S., 2010). The Water Quality Index shows critical negative values in the upper Paraná watershed (Tietê and Iguaçu Rivers) located in the south and southeast regions. The cost of water treatment in the watersheds of the southeast and south regions is very high (more than 200 US dollars/1,000m^3). The Trophic State Index for Brazil is also high in the southeast and south regions. Eutrophic and hypereutrophic waters in these regions are a source of heavy expenses with regards to water treatment, impairing multiple uses such as recreation, tourism and fisheries (Tundisi et al., 2006).

As a general trend, the surface and ground waters of watersheds of the South, Southeast and Northeast have a low Water Quality Index and a high Eutrophic Index as a result of human activities and the concentration of waste water and toxic substances and elements (FIG. 6 and FIG. 7).

In certain regions of the country, such as in some reservoirs of the Paraná and São Francisco watersheds, the use of water for fisheries, recreation and to supply the population was prohibited due to the heavy degradation.

The degradation of water quality in Brazil can also be aggravated due to hydrologic extremes. For example, with heavy rains and high discharge in urban and metropolitan regions, contamination can increase three to four times its usual (Tucci & Mendes, 2006; IIEGA/PMSP, 2009). During extreme events of dryness in the Northeast, eutrophication in reservoirs, used for storage of drinking water and for quenching animal thirst, can frequently be a source of water quality degradation.



SOURCE ANA 2009

FIG. 6. Percentage of Treatment of Wastewater in Brazil

A general overview and trend of the capacity of assimilation of organic discharge also shows a picture that matches the Water Quality Index and the Trophic State Index; the surface and ground waters of the watersheds located in the south and southeast region have low capacity of assimilation of organic discharge, whereas in the Amazon region watersheds have high capacity for assimilation of organic discharge (78% of the Amazonian rivers) (ANA 2009).

SOURCE: MOSS & MOSS 2005

FIG. 7. The Scenario of the Water Quality in Brazil 2007

6. The Institutional Development of Water Resources Management

The Brazilian water law was edited by the Federal Government in 1997 (law 9.433 of January 8th, 1997). From that year on, until 2007 all 27 Brazilian states, edited their water law. The Brazilian water law promoted several advances in the integration of management of water resources in Brazil: first an ample decentralization process was put into practice, with each state implementing their own watershed committees consolidating their plans and their watershed agencies. In addition they created a plan for the economic development of the watersheds and for the use of water, and formed state agencies responsible for controlling pollution and water contamination. The advances in the legislation were registered in regions or states where water conflicts over water uses and water availability existed (ANA, 2002).

The process of institutionalization, therefore is more advanced in the south, southeast and northeast watersheds where initial problems already occurred. The National System of Integrated Water Management in Brazil consists of the National Council for Water Resources, the Secretary of Water Resources of the Ministry of Environment, the National Water Agency, the State Councils for Water Resources, the State Agencies and the Watershed Committees and Watershed Agencies (Braga, et al., 2006).

The consolidation of the institutional framework in Brazil is also due to the establishment of mechanisms to support research and development in the water sector: The implementation of the sectorial funds on water resources, which allocates 1% of the profit of private business in water to support projects on mineral research, hydroelectricity and environmental problems, was a major achievement. These sectorial funds, established in 1999, enabled scientific and technological development, which supported the work of the watershed committees and agencies. Therefore financial resources are now adequate for the expansion of water research and for technological advances.

These advances at federal and state levels were not followed by the organization of the water management at the municipal level; therefore, this is one of the major challenges needed to be addressed in the water policy in Brazil. Another relevant challenge is the need to establish adequate pricing mechanisms. For example, agricultural use of water is heavily subsidized thus preventing better and more efficient use of water for food production.

For the interstate watersheds, plans for water resource management are in progress but show slow advances. The specification of desired standards of water quality of the rivers, lakes and reservoirs related to the multiple uses of water, is also slow, considering the economic pressure for more water withdrawals in different sectors of activities.

The licensing for water withdrawals has been in progress since the editing of the water law in 1997. This authorization is given by the National Water Agency and includes all multiple uses such as public supply of water, extraction of ground water for several purposes, hydroelectricity and food production. Currently water license for withdrawals has been given to 3.520m^3/s in several of the twelve watersheds of Brazil (ANA, 2009). The largest water withdrawals licenses were granted in the Paraná watershed (1,300m^3/s).

The National System of Information for water resources in Brazil is coordinated by the National Water Agency and started to be implemented in the year 2000. This system consists of four major components: subsystem of use and regulation; subsystem of planning and management; subsystem of quality and quantity and a subsystem of "water intelligence"(geographical/territorial information and documentation on water resources). Water pricing is at present implemented in four watersheds, in Brazil, with a tendency to improve and be established in federal and state rivers.

7. Challenges for the Water Policy in Brazil

7.1 Social Challenges

Despite the institutional progress in the organization of the integrated water resources management in Brazil, huge problems still exist with regards to proving water and sanitation services to the entire population. The water availability is relatively good, with about 80% of the population being supplied with clean water. But the sanitation problem is enormous and complex. With only 30% of the wastewater being treated and very poor systems of solid waste disposal and removal, the contamination of surface and ground waters are high and severely impact human health (ANA, 2009). As expressed in OECD (2003), "many social issues involved in water management", (pp. 33 "key trends and challenges") can be analyzed in terms of "equity".

This means equity among income groups. In Brazil poorer consumers can be found paying more for the water due to an inefficient distribution system. And in the surroundings of the urban areas of all metropolis of Brazil (São Paulo, Rio de Janeiro, Salvador, Recife, Porto Alegre, Belém, Fortaleza and Manaus), around 30 million people need adequate sanitation (solid waste disposal and wastewater treatment) (Tundisi &

Matsumura-Tundisi, 2010c). The current situation of urban rivers is a picture of this problem: most urban rivers in large cities or small towns are polluted and degraded and need urgent projects for restoration and recovery (Tucci and Mendes, 2006).
There is also a disparity among regions with regards to having access to water services and wastewater treatment. Rural populations are affected in many regions of Brazil with regards to having limited access to water and sanitation services. Consumption levels also show disparities among regions in Brazil (Rebouças, et al., 2006).

The large scale deficit in sanitation in Brazil is thus a social challenge of the highest priority, concerning reduction of vulnerability of periurban populations. Diseases generated from poor water distribution or non treatment of wastewater is high. The changes in the hydrosocial cycle as a consequence of human activities such as the construction of reservoirs, are not yet well understood in Brazil and efforts to measure the impacts, reduce or remove them are needed especially considering the expansion of the hydroelectricity production (Tundisi and Campagnoli, in preparation).

7.2 Integrated Water Resources and Watershed Management

Efforts to implement an integrated policy for the management of water resources at watershed level in Brazil have to be enhanced through the support of the large scale decentralization program which is currently in progress. This will include attention to surface and ground water management, and the promotion of an integration of biogeophysical data, soil uses, agricultural activities and water quality of streams, large rivers, reservoirs and lakes (Braga, et al., 2006; Tucci, 2007). The pressure to increase food production is becoming a threat to natural areas of forests, riparian vegetation and wetlands. Removal of vegetation by increasing the area of agriculture is one of the urgent problems to be solved by both the municipalities and the federal and state agencies. Changes in water quality of surface water due to the removal of riparian forests, mosaics of vegetation and wetlands were demonstrated recently (Tundisi & Matsumura-Tundisi, 2010b). A modification of the forest protection law in benefit of agriculture production is in discussion in the Brazilian Congress, mobilizing society, the Brazilian Academy of Sciences and scientists in order to stop changes that will be harmful to the water availability and quality as well as to biodiversity.

On the other hand there are several initiatives to improve reforestation by promoting incentives to farmers. These initiatives at municipal level are being adopted in many regions of Brazil and will undoubtedly be countermeasures to the deforestation process and the possible changes in the federal law. In many Brazilian towns of 200,000 to 500,000 inhabitants, the proposal for the protection of areas that are important to water supply and aquifer recharge have been made, creating new opportunities for improving water management. The improvement of the practices of river basin management, adopting the ecosystem approach, is a step that is being incorporated in water management initiatives in Brazil. Though this is still a relatively slow process, this concept is already established in several states and regions reflecting a positive trend in the necessary advances for management (IIEGA/PMSP, 2009).

7.3 Protection and Restoration of Surface and Ground Waters

The large scale of contamination and pollution in Brazil is a consequence of a long term process of watershed degradation, discharge of wastewater, excessive soil uses and toxicity impacts. The degradation of the ecological values and services of freshwater ecosystems is followed by a general increase in the vulnerability of populations (urban and rural) to toxic chemicals and pathogens. The capacity of fish production in rivers, reservoirs and lakes has been impaired by this deterioration either directly, by producing mass mortality, or indirectly, by stopping consumption of contaminated fish, crustaceans and mollusks (Tundisi, et al., 2006). Dealing with invasive species is another management priority. Mollusks such as Limnoperna fortunei (mussel) and fishes introduced from other continents or even other watersheds in Brazil are considerably changing the structure of food chains and in the organization of the ecological network in rivers, lakes, and reservoirs, with impacts on fisheries (Rocha, et al., 2005).

Additionally, the intensive development of aquaculture with non native species is an impact of considerable magnitude in several watersheds in Brazil. Technologies for restoration of watersheds need to be introduced at a larger scale in Brazil (Zalewsky, 2007).

Ecohydrological technologies combined with ecological processes can reduce costs of restoration, prevent floods and inundations and can be a new alternative technology to be applied in many regions of Brazil (Straskaba & Tundisi, 2008). In urban and metropolitan regions ecohydrological technologies are in progress (IIEGA/PMSP, 2009), though still very limited to a few experiences.

7.4 Climate Change and Water Resources

For the last 10 years, studies on the variability of climate and climatic changes in South America and in Brazil are being developed with great intensity. Variations in rainfall and discharges in the Amazon and Northeast Brazil show interannual and decadal patterns. These variations are more important than the trends for the constant reduction of rainfall (Marengo, 2006). Variability is associated to patterns of oscillation related to the El Niño (ENOS), the Pacific Decadal Oscillation – PDO, The North Atlantic Oscillation – NAO and the variability of Tropical and South Atlantic.

Impacts of the El Niño or La Niña have been observed in the north and northeast regions (dry periods) and South Brazil (dryness during La Niña and excess rainfall and floods during El Niño). With the increase of the frequency or intensity of El Niño, Brazil will be subject to more dry periods or floods or warmer spells (Marengo & Nobre, 2001; NAE, 2005 a,b; Marengo & Silva Dias, 2004a).

The phenomena of El Niño and La Niña in the Equatorial Pacific, and the meridional gradient of the temperatures (temperature at sea surface) over the Tropical Atlantic are responsible, in great part, for the interannual

variability of climate in South America. Cold fronts from Antarctica affect the climate of the south and southeast regions and the ecological and limnological functioning of lakes, rivers and reservoirs (Tundisi, et al., 2004, 2006, 2010). One important achievement in the studies of the water flux in Brazil was the understanding of the fundamental role the Amazon region plays on the water balance and hydrological cycle of central and southeast areas of Brazil. Marengo, et al. (2004 a) have proposed a conceptual model, with jetts of moisture being transported from the Amazon to the Southeast and la Plata basin (FIG. 8).
The climate changes in Brazil and the impacts on the hydrological cycle, water distribution, floods and dry periods, have to be understood against a large scale of land use, deforestation and increased and inadequate solid waste disposal. For example, a synergy between untreated wastewater and the warming of surface temperature in lakes and reservoirs, could result in heavy blooms of cyanobacteria and increase in the frequency of toxic blooms as discussed by Tundisi, et al. (2010).

The "savanization" of the Amazon could result in 30% less water for the south and southeast regions of Brazil, with enormous social and economic impacts. Changes in discharge of rivers of the Pantanal (largest wetland in the world 200,000 km^2) were already observed by Tucci (2003) and Tucci & Braga (2003). The impacts of climatic changes can affect human health, also, due to the increase in the number of temporary ponds and the growth of vectors of water borne diseases (NAE, 2005 a,b). The water policy in Brazil is addressing some of the problems related to possible climatic changes and their impacts in the water quantity and water distribution.

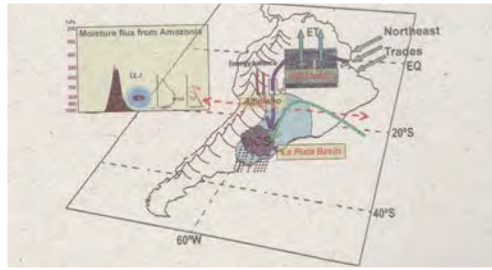


FIG. 8. The Moisture Flux from Amazonia to the Southeast Accordingly to the Conceptual Model of Marengo el al (2004 a)

The - Nucleo de Assuntos Estratégicos da Presidência da República – the Nuclei for Strategic Studies of the Presidency of Brazil has developed studies, scenarios and trend analysis in order to promote policies for adaptation and mitigation of the impacts of climatic changes such as large floods in urban areas or long dry periods in certain regions (Tucci and Mendes, 2006, Tucci, 2007).
Seminars on climatic changes and possible impacts on the water resources led to discussions and proposals for the intensification on modeling efforts in order to develop more accurate scenarios of consequences of climatic changes in the hydrological cycle and on the economy (Tundisi, 2010, in press).

7.5 The Hydrological Extremes and Impacts in Brazil

In the last five years hydrological extremes combined with inadequate use of land and watershed deterioration have caused many disasters in Brazil with loss of lives and properties. In January 2011 landslides due to heavy precipitation, well above the average for Southeast Brazil, claimed 1.000 lives and economic losses of U$500 million (FIG. 9). The FIG. 9 shows the extension of the cold front in Southeast Brazil that resulted in disasters on January 13th 2011. This was a result of cold fronts from the Antarctic with a contribution of excess moisture from the Amazon resulting in heavy rains and excess drainage. The prevention of these disasters, by removing people from potential areas of impact, by educating decision makers to apply correct public policies, by creating artificial wetlands and areas of water retention, is an urgent need (Tucci and Braga, 2003, Tucci, 2007). The potential population in Brazil subject to these disasters and living in areas of risk is 20 million people. The prevention of these disasters should be a priority in the water policy in Brazil, articulated with territorial and regional studies and water management.

7.6 Contamination of Coastal Waters

The concentration of the human population in urban and metropolitan areas resulted, as shown, in the contamination of rivers, lakes and reservoirs in an unprecedented scale. Since most of the Brazilian population is also concentrated near or in the coastal areas, contamination of estuaries, bays and coastal waters is also increasing. Lacerda et al (2008) have shown that nitrogen and phosphorus from anthropogenic sources are producing an over enrichment of the estuaries along the Ceará, state coast in Northeast Brazil. This is mainly due to urban runoff and solid waste disposal affecting surface waters. Evidence of contribution of non point emissions of Cd and Zn contamination in Sepetiba Bay (Southeast Brazil), confirm the quantitative importance of these sources (Lacerda and Molisari, 2006). Recovery of estuaries, impacted by point and non point sources of contaminants and nutrients originated in urban regions near coastal areas, is urgently needed.

7.7 Improvement of Drinking Water Quality, Risk Control and Vulnerability Reduction

Contamination of drinking water due to poor infrastructure occurs in Brazil in large and small towns. The most common cause is the contamination of the distribution systems. Corrosion of pipes, damages to pipes due to construction or repairs, low pressure on pipes, all lead to outbreaks of waterborne diseases. Inadequate control of chemical substances and inadequate filtration are other causes.

There is a need to improve the technical quality of the distribution and water treatment systems. Monitoring of water quality at the catchment (introduced in the year 2000), was a significant policy implemented for the control of water contamination in Brazil, assisting in the determination of adequate treatment for drinking purposes. This is a compulsory law enforced in all of Brazil (Tundisi & Matsumura-Tundisi, 2010c).

The control of water quality for drinking purposes also needs the implementation and introduction of advanced technology in order to establish limit standards to the presence of persistent organic pollutants (POPs). Increased risk and vulnerability of human population to dissolved organics and viruses have to be considered in the development of new molecular techniques.

7.8 Strategic Studies

7.8.1 Hydroelectricity

Strategic studies on the use of hydroelectricity should address the Amazon region that could potentially supply, in the future, 70% of the hydroelectricity of Brazil. This must be considered regarding biodiversity loss, greenhouse gas emissions, and change in the hydrosocial cycle in the river morphology and flow. As the aquatic fauna of rivers is severely impacted by reservoirs, the large catfish living in the tributaries of the Amazon can be affected running the risk of depletion of stocks and even extinction. Therefore the location, engineering, retention time, volume and inundated areas of reservoirs should be strategically studied in order to preserve important areas of mega biodiversity and the hydrosocial cycle (Tundisi and Campagnoli, in preparation).

7.8.2 Water and Economy

The relevance of the national water resources in the economic development of Brazil is well known. Water is fundamental for food production, hydroelectricity, navigation, recreation and fisheries. Studies on the relationship between the limits of economic growth and the surface and ground water availability are required. The use of economic instruments to manage water resources (such as the water polluter pays or the water consumer pays principles) requires further strategic studies (Canepa, et al. 2006, Hartman, 2010).

7.8.3 The Social and Economic Impact of Hydrological Changes and Extreme Conditions

As referred by Tucci (2007), the management of risks related to natural disasters has social and economic implications that need to be analyzed. Between 1994 and 2003 losses due to natural disasters amount to 6.8 billion U$ dollars in all countries. The recent trend in the growth of natural disasters is due to the increase of the population in areas of risk, increase of urban growth and variability of the hydrological cycle associated to climatic changes. In Brazil with 80% of the human population located in metropolitan regions or urban areas, infrastructure and soil use are deteriorated especially in the periurban areas of midsize (< 1,000,000 inhabitants) or larger metropolis (> 5,000,000 inhabitants). Areas of risk are extensive and the population considered vulnerable amounts to about 20 million inhabitants. The fragmentation of the watersheds due to urbanization is a reality, generating consequences on the water cycle, floods and the deterioration of water quality. Strategic studies on these impacts, development of alarm systems, and removal of populations are urgent actions needed to improve the National water policy.

FIG .9. Cold Front in Southeast Brazil on January 13th 2011 (http://satelite.cptec.inpe.br/acervo/loop/?idFonte=14.)

7.9 Water and Human Health

In Brazil many water borne diseases still persist despite national government efforts or regional actions. Schistosomiasis, Leptospirosis intoxication by toxins of cyanobacteria, and dengue fever are diseases that affect millions of people all over Brazil, especially in periurban areas and rural villages (700,000 cases of dengue fever in 2008 and 8,000,000 infected with Schistosomiasis all over the country (Confalonieri, et al. 2010). One relevant development in the area of water resources and human health is the management of contamination and the adoption of targets to reduce morbidity and mortality due to lack of sanitation. Children of one up to five years of age are affected by water borne disease causing high infant mortality. The development of an index of water/human health/environment could be very helpful in the setting up of targets based on concrete actions and measures (Confalonieri et al. 2010).

7.10 The Amazon and Northeast Regions of Brazil

An integrated management of water resources in the Amazon region is a priority.

The characteristics of this region consisting of high rainfall, abundant discharge of rivers (Amazon River 225,000 m3/s), interactions of rivers and forests and high biodiversity are relevant natural assets of Brazil. Investment in Science and Technology in the Amazon and the further development of ecological studies articulated with economic evaluations of the "natural capital" and ecosystem services, and a better knowledge of the hydrosocial cycle - such as the Homo sapiens interaction with the water and ecosystems - is a priority. Efforts in capacitating technical staff of scientists and water managers are essential (Val, et al., 2010).

An equally relevant challenge is the semiarid region of Northeast Brazil. This is the home of 30 million people that suffer from water scarcity on a daily basis. The São Francisco River, which is the most important water source for the Northeast, is now suffering a process of water depletion, contamination by heavy metals and toxic substances, and water discharge. The waters of the São Francisco River are now being transferred to the eastern and western parts of the northeast region, through a series of artificial channels (26 m^3/s). This could change the economy and the life quality of millions of people. Notwithstanding, the success of this process depends on close evaluation of the development programs and human capacity building.

7.11 International Watersheds

Brazil and 4 other countries (Argentina, Bolívia, Paraguay, Uruguay) share the La Plata Basin with, 3,000,000 $km^2$and 120 million inhabitants. The Amazon Basin shared by Ecuador, Peru, Colombia, Venezuela, French Guiana, British Guiana and Suriname, has 5,000,000 km^2, scarce population and abundant water supply.

In the water policy of Brazil, the integration with these countries in the sharing of water resources is essential for future economic development and future multiple uses.

7.12 Research Needs

There is a need to include Science, Technology and Innovation in the planning and implementation of integrated water resources management. Research, technology and innovation are essential components of the integrated management process. Improving technology for eutrophication and contamination abatement, development of new desalination technologies and water reuse, and implementation of data banks of national and regional levels constitute major challenges.

Integration of ecologists, engineers and limnologists is needed for these advances (Hespanhol, 2010, Tundisi & Matsumura-Tundisi, 2010a). Research to support technical criteria for adoption of measures for protection and vulnerability of aquifers is also needed (Hirata et al., 2010). Additionally, the development of guidelines of contamination based on bioindicators, ecological and limnological studies at different watersheds are needed (Bere and Tundisi, 2010, Tundisi, et al., 2010a).

8. Conclusions

The water policy in Brazil considering present and future perspectives was discussed in this document. Brazil is a country with abundant water resources unevenly distributed in relation to the distribution of population and economic activities. Water uses in Brazil are diversified with approximately 70% used in agriculture and 30% in water supply for human uses, industries, fisheries, recreation, tourism, navigation and hydroelectricity.

The Brazilian water law was established in 1997 and the implementation of integrated water resources management has evolved since then. In 10 years, the 27 states in Brazil have established councils for water management and systems of water management throughout the watershed committees. In 2001 the National Water Agency was founded with the objective to coordinate actions at federal level, and help implement the integrated water management process at each region with federal rivers and each state of the Brazilian federation. Despite considerable advances at institutional level and a continuous search for efficiency and decentralization, problems remain.

Brazil water policy challenges:

- Further efforts to implement integrated watershed management at the watersheds (state and national watersheds).
- Adopt water quality targets, sanitation targets (domestic wastewater treatment and solid waste disposal and treatment), in order to reduce risk and vulnerability especially of periurban and rural populations.
- Promote heavy investments at federal, state and municipal levels to reduce water contamination by fertilizers, pesticides and toxic metal.
- Develop strategies for solving conflicts over multiple water uses: hydroelectricity in areas of high biodiversity (as the Amazon region), regional impacts on the hydrosocial cycle, growth of agriculture and deforestation, with impacts on water sources for public supply.
- Develop and stimulate strategic studies in water resources, economic development and the use of economic instruments for integrated water resources management (the polluter pays and the consumer pays principles).
- Promote integrated watershed management, with an ecosystem concept introducing new and less costly technologies such as ecohydrology and ecotechnologies. These management practices can be articulated with ecological studies and the introduction of technologies for recovery of streams, urban rivers, large rivers, and protection of aquifers.
- Promote studies for the economic evaluation of freshwater ecosystem services such as the role of wetlands and riparian forests in the maintenance of water quality and water quantity and maintaining biodiversity.

- Develop strategies, study groups and implement actions for the reduction of the impact of disasters of hydrological origin due to climatic changes and inadequate land use. This includes risk analysis of critical areas.
- Improve research on biological indicators, on modeling of aquatic ecosystems and the studies and strategic evaluations of the future of water resources, quality and quantity and water reuse.
- Promote and implement adaptive management strategies to cope with the impacts of climate change on the hydrological cycle, water availability and water supply.
- Provide support to improve capacity building of managers and technology transfer to all regions of the country and develop actions for mobilizing public participation at watersheds level, promoting education on water resources issues for all the Brazilian population.
- The Amazon and northeast regions of Brazil should have special attention considering the peculiar characteristics of their hydrosocial cycles, the extreme dependence on water for local and regional development and the need for a national capacity building effort in these regions.
- Promote studies, evaluating the impact of the use of ground water. Promote the monitoring of the quality of ground water and manage over exploitation in certain regions.
- Develop water resources management at internationally shared watersheds, as part of the water policy of Brazil.

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9. References

1. Abe S., D.; Sidagis-Galli, C.; Matsumura-Tundisi, T.; Tundisi, J.E.M.; Grimberg, D.E.; Medeiros, G.R.; Teixeira-Silva, V.; Tundisi, J.G. (2009). The effect of euthrophication on greenhouse gas emissions in three reservoirs of the Middle Tietê River, Southeast Brasil, Verhandlugen Internacionale Vereinigung Limnologie, Vol. 30, Part 6, pp. 822-825.
2. Agência Nacional das Águas (ANA) (2009). Conjuntura. Recursos Hídricos no Brasil. Brasília, D.F., pp 203.
3. Agência Nacional das Águas 2002. A evolução da gestão de recursos hídricos no Brasil/The evolution of the Water Resources Management in Brasil, Brasília, 64 pp.
4. Azevedo, S.M.F.O. (2005). South America: toxic cyanobacteria. In: Codd,G.A., Azevedo, S.M.F.O., Bagchi, S.N, Burch, M.D., Carmichael, W.W., Harding, W.R., Kaya, K. & Utkilen, H.C. (Eds.). Cyanonet: a global network for cyanobacterial bloom and toxin risk management, IHP-Unesco, Paris, pp. 115-126.
5. Bere, T. and Tundisi, J.G. (2011). Influence of ionic strength and conductivity on benthic diatom communities in tropical river (Monjolinho), S. Carlos, SP. Brasil, Hydrobiologia, Vol. 661, pp. 261-276.
6. Bicudo, C.E.M.; Tundisi, J.G.; Cortesão S., Marcos (Eds.) (2010). Águas do Brasil: analyses estratégicas, Academia Brasileira de Ciências. Secretaria Meio Ambiente Estado de São Paulo, p. 222.
7. Braga, B.; Flecha, R; Pena, S.D.; Felman,

J. (2006). A reforma institucional do setor de recursos hídricos. In: Rebouças, A.; Braga, B.; Tundisi, J.G, (Eds.). Águas doces no Brasil: capital ecológico, uso e conservação. Escrituras Editora, São Paulo, pp. 639-673, (3ª edição).

8. Braga, B.; Porto, M. & Tucci, C. (2006). Monitoramento da quantidade e qualidade das águas. In: Rebouças, A.; Braga, B.; Tundisi, J.G, (Eds.). Águas doces no Brasil: capital ecológico, uso e conservação, Escrituras Editora, São Paulo, pp. 146-160 (3ª edição).
9. Cánepa, E.M.; Pereira, S.J.; Lana, E.L. (2010). Água e Economia. pp. 43-54. In: Bicudo, C.E.M.; Tundisi, J.G.; Cortesão S., M. Orgs. Águas do Brasil: Análises estratégicas, Academia Brasileira de Ciências, Secretaria Meio Ambiente, Estado de São Paulo. 222 pp.
10. Confalonieri, U.; Heller, Azevedo, S. (2010). Água e saúde: aspectos globais e nacionais, pp.27-38. In: Bicudo, C.E.M.; Tundisi, J.G.; Cortesão S., M. Orgs. Águas do Brasil: Análises estratégicas, Academia Brasileira de Ciências, Secretaria Meio Ambiente, Estado de São Paulo, 222 pp.
11. Hartman, P. (2010). A Cobrança pelo uso da Água como instrumento economico da Política Ambiental, Aeba, p. 497.
12. Hespanhol, I. (2010). Conservação e reuso como instrumentos de gestão para atenuar os custos de cobrança pelo uso da água no setor industrial, pp. 59-76, In: Bicudo, C.E.M.; Tundisi, J.G.; Cortesão S., M. Orgs. Águas do Brasil: Análises estratégicas. Academia Brasileira de Ciências, Secretaria Meio Ambiente, Estado de São Paulo, p. 222.
13. Hirata, R.; Gomes Zoby, J.L.; Oliveira de, F.R. (2010). Água subterranean: reserva estratégica ou emergencial, pp. 149-161. In Bicudo, C.E.M; Tundisi, J.G.; Cortesão S., M. Orgs. Águas do Brasil: Análises estratégicas. Academia Brasileira de Ciências, Secretaria Meio Ambiente, Estado de São Paulo. p. 222.
14. IIEGA/PMSP (2009). Manual de gerenciamento de bacias hidrográficas, p. 134, São Carlos/São Paulo.
15. Instituto de Estudos Avançados (2008). Dossiê Água. Universidade de São Paulo, 336 pp.
16. Jorgensen, J.E.; Lofler, H.; Rart, W.; Straskraba, M. (2005). Lake and reservoir management, Elsevier, Amsterdam, 502 pp.
17. Lacerda, L.D; Molisani, M.M.; Sera, D; Maria, P.L. (2008). Estimating the importance of natural and antropogenic sources on N and P emission to estuaries along the Ceará State Coast. N.E of Brasil. Environ. Mon.t.Ass. Vol. 141, pp. 149-164.
18. Lacerda, L.D. and Molisani, M.M. (2006). Three decades of Cd and Zn contamination in Sepetiba Bay SE Brasil: evidence from the mangrove oyster Crassoscrea rhizophorae, Mar. Poll. Bull., Vol. 52, pp. 969-987.
19. Marengo, J.A. (2008). Água e Mudanças climáticas. pp. 83-96, In: Dossiê Água. Inst. Estudos Avançados, U.S.P., 336 pp.
20. Marengo, J.A. (2006). Mudanças climáticas globais e seus efeitos sobre a biodiversidade, IBAMA, 212 pp.
21. Marengo, J.A.; Silva Dias, P. (2006). Mudanças climáticas e globais e seus impactos nos recursos hídricos. Capítulo 3 em Águas Doces do Brasil: Capital Ecológico, uso e Conservação, pp. 62-

109. Rebouças, B. Braga, J. Tundisi (Eds.), Editora Escrituras, SP
22. Marengo, J.A.; Soares, W.R; Saulo, C.; Nicolini, M. (2004a). Climatology of the Low-Level Jet East of the Andes as derived from the NCEP-NCAR reanalysis, Journal of Climate, 17, pp. 2261-2280.
23. Marengo, J.A. e Soares, W.R. (2003). Cap. 6, Impacto das mudanças climáticas no Brasil e possíveis futures cenários limáticos: síntese do terceiro relatório do IPCC, pp. 209-242. In: Tucci, E.M.C. e Braga, B. (organizadores) (2003). Clima e Recursos Hídricos no Brasil, ABRH.ANA, Forum Brasileiro de Mudanças Climáticas, p. 348.
24. Marengo, J.A.; Nobre, C.A. (2001). The Hydroclimatological framework in Amazonia. In: Biogeochemestry of Amazônia, Richey., McClaine, M., Victoria, R. (Eds.), pp. 17-42.
25. Moss, G. e Moss, M. Eds. (2005). Brasil das Águas. Revelando o Azul do Verde e Amarelo, Petrobrás, 153 pp.
26. NAE (2005a). Mudança de Clima, Vol.I, Negociações internacionaos sobre a mudança de clima; vulnerabilidade, impactos e adaptação à mudança de clima, Cadernos NAE, Núcleo de Assuntos Estratégicos da presidência da República, NAE-SECOM, 2005. Brasília, 250 pp.
27. NAE (2005b). Mudança de Clima, Vol.II: Mercados de Carbono. Cadernos NAE, Núcleo de Assuntos Estratégicos da presidência da República, NAE-SECOM 2005, Brasília, 500 pp.
28. OECD (2003). Improving water management: recent OECD, Experience, IWA Publishing, 128 pp.
29. Rebouças, A.; Braga,B.; Tundisi, J.G. (2006). Águas doces no Brasil: Capital ecológico, usos e conservação. Escrituras Editora, S. Paulo, 732 pp, (3ª edição).
30. Rocha, O.; Espíndola, E.; Fenerich-Verani, N.; Verani, J.R.; Rietzler, A.C. (2005). Espécies invaspras de água doce: estudos de caso e propostas de manejo. EDUFSCAR, 416 pp.
31. Sidagis-Galli, C.; Abe S., D.; Teixeira-Silva, V.; Medeiros, G.R.; Brum, P.R.; Cimbleris, A.C.P. (2009). Greenhouse gas concentration and diffusive flux at the sediment-water interface from two reservoirs in Brasil, Verhandlugen Internacionale Vereinigung Limnologie, Vol. 30, Part 6, pp. 830-833.
32. Straskraba, M; Tundisi, J.G. (2008). Diretrizes para o gerenciamento de lagos, Vol. 9, Gerenciamento da qualidade da água de represas (2ª Edição), ILEC/IIE, 300 pp.
33. Tucci, C.E.M. (2010). Urbanização e Recursos Hídricos. pp-113-128. In: Bicudo, C.E.M.; Tundisi, J.G.; Cortesão S., Marcos (eds.) Águas do Brasil, Análises Estratégicas, Academia Brasileira de Ciências, Secretaria do Meio Ambiente, Estado de São Paulo, p. 222.
34. Tucci, C.E.M. (2007). Inundações urbanas, ABRH; RHAMA, 389 pp, (1ª edição).
35. Tucci, C. & Mendes, A.G. (2006). Avaliação Ambiental integrada de bacias hidrográficas, MMA, PNUD, 311 pp.
36. Tucci, E.M.C & Braga, B. (Orgs.) (2003). Clima e Recursos Hídricos no Brasil, ABRH, ANA, Forum Brasileiro de Mudanças Climáticas, 348 pp.
37. Tucci, E.M.C. (2003). Recursos hidrológicos e os impactos do uso do solo, pp. 31-76. In: Tucci, C.E.M., Braga, B. Orgs. Clima e

Recursos Hídricos no Brasil, ABRH, ANA, GWP, Forum Brasileiro de Mudanças Climáticas, 348 pp.
38. Tundisi, J.G. & Campagnoli, F. (2011). How many more dams in The Amazon? (in preparation).
39. Tundisi, J.G. e Matsumura-Tundisi, T. (2010a). Ciência, Tecnologia, Inovação e Recursos Hídricos: oportunidades para o futuro, pp. 179-197. In: Bicudo, C.E.M.; Tundisi, J.G.; Cortesão S., Marcos (eds.) Águas do Brasil, Análises Estratégicas, Academia Brasileira de Ciências, Secretaria do Meio Ambiente, Estado de São Paulo, 222 pp.
40. Tundisi, J.G. & Matsumura-Tundisi, T. (2010b). Potential impacts of changes in the forest law in relation to water resources, Biota Neotropica, Vol. 10 n° 4 (in press).
41. Tundisi, J.G. & Matsumura-Tundisi (2010c). Recursos Hídricos no século 21, Oficina de Textos (in press), new edition.
42. Tundisi, J.G.; Matsumura-Tundisi, T.; Pereira, K.C.; Luzia, A.P., Passerini, M.D.; Chiba, W.A.C.; Morais, M.A.; Sebastien, N.Y. (2010). Cold fronts and reservoir limnology: an integrated approach towards the ecological dynamics of freshwater ecosystems. Braz. J. Biol. Vol. 70, n° 3, Supl. 0, Sao Carlos Oct. 2010.
43. Tundisi, J.G. & Matsumura-Tundisi, T. (2008). Limnologia, Oficina de Textos, SP, 632 pp.
44. Tundisi, J.G.; Sebastien, N.Y.; Matsumura-Tundisi, T.; Tundisi, J.E.M. & Manzini, N.F. (2006). The responses of reservoir of Southern Brasil to the passage of cold fronts as reflected by physical, chemical and biological variables. Verhandlugen Internacionale Vereinigung Limnologie, Vol. 29, pp. 2124-2128.
45. Tundisi, J.G.; Matsumura-Tundisi, T.; Galli, C.S. (2006) (eds.) b) Eutrofização na América do Sul: causas, conseqüências e tecnologias para gerenciamento de controle. São Carlos: Instituto Internacional de Ecologia, Associação Instituto Internacional de Ecologia e Gerenciamento Ambiental, Eutrosul, 531 pp.
46. Tundisi, J.G. (2005). Águas futuras: o futuro dos recursos hídricos no Brasil, pp. 148-153. In: Moss, G. e Moss, M. (Eds.), Brasil das Águas. Revelando o Azul Verde e Amarelo, Petrobrás, 153 pp.
47. Tundisi, J.G.; Matsumura-Tundisi, T.; Arantes Junior, J.D.; Tundisi, J.E.M.; Manzini, N.F. and Ducrot, R. (2004). The response of Carlos Botelho (Lobo/Broa) reservoir to the passage of cold fronts as reflected by physical, chemical and biological variables, Brasilian Journal of Biology, Vol. 64, n° 1, pp. 177-189.
48. UNESCO/IHP (2004). Integrated water-shed management. Ecohydrology &Phyto-technology Manual. UNEP/IETC, 246 pp.
49. UNESCO, UNEP (2008). Water Quality for Ecosystem and Human Health. IAP, ERCE, GEMS, Water, 120 pp.
50. Val L.; A. et al. (2010). Amazônia: recursos hídricos e sustentabilidade, pp. 95-112. In: Bicudo, C.E.M.; Tundisi, J.G.; Cortesão S., M. (Eds.). Águas no Brasil: análises estratégicas, Academia Brasileira de Ciências, Secretaria do Meio Ambiente Estado de São Paulo, 222 pp.
51. Zalewski, M. (2007). Ecohydrology in the face of anthropocene, Vol. 7, n° 2, pp. 99-100.

Peak covered with snow, Coast Range near Whistler, British Columbia, Canada

Water Resources in Canada

A Strategic Viewpoint

Keith Hipel[1], Andrew D. Miall[2], Daniel W. Smith[3]

[1]Former Vice President of the Canadian Academy of Science, Royal Society of Canada, Senior Fellow, Centre for International Governance Innovation, University Professor, Department of Systems Design Engineering, University of Waterloo, Waterloo, Ontario, Canada

[2]Former President of the Canadian Academy of Science, Royal Society of Canada, Gordon Stollery Chair in Basin Analysis and Petroleum Geology, Department of Geology, University of Toronto, Toronto, Ontario, Canada

[3]Director, Applied Science and Engineering Division, Academy of Science, Royal Society of Canada, Professor Emeritus, Department of Civil and Environmental Engineering, Cross Appointment, School of Public Health, University of Alberta, Edmonton, Alberta, Canada

1. Introduction

All levels of government in Canada should adopt an adaptive, integrative and participatory approach to water governance from a systems thinking perspective for proactively addressing existing strategic water problems as well as unforeseen difficulties that will arise in the future. In consultation with all levels of government and key stakeholders, Canada should develop a comprehensive national water policy that reflects the values of Canadians and has precedence over international trading agreements. Because of its vastness and the rich diversity of climate regions and ecosystems, Canada has many regional water problems to solve such as melting glaciers in the Rocky Mountains, droughts in the Prairies, high water demand in the oil sands, flooding in Manitoba, fluctuating water levels and pollution in the Great Lakes, expanded hydroelectric power developments in northern Quebec and Labrador, and the threat of water exports, especially from the Great Lakes.

A wide variety of challenging water-related problems to tackle occur in many regions of Canada: groundwater over-exploitation, contaminants of emerging concern, brownfield prevention and redevelopment, bottled water, and the increasing negative impacts of climate change. Accordingly, specific recommendations are put forward for achieving enlightened water governance in Canada as well as internationally. Moreover, connected governance innovations related to climate change, energy and trade are also formulated.

2. Overall Water Situation in Canada

Canada has a reputation of being blessed with vast quantities of freshwater, given the many prominent bodies of water that feature on its landscape, including the Great Lakes, many other giant lakes (Great Slave, Great Bear, Winnipeg) and the thousands of lakes dotting the Canadian Shield (FIG. 1). In light of this apparent abundance of water, it is not overly surprising that Canadians use an enormous amount of water in comparison to other nations. The per-capita use of water by Canadians (including agricultural, industrial and domestic sectors) is second only to that of the United States, and at least double that of European countries (Boyd, 2001). Unfortunately, however, this perception of plenty is largely unfounded. The data show that Canada ranks a distant third, behind Brazil and the Russian Federation, in total renewable water resources, at 6.5% of the global total (Sprague, 2007). Moreover, most of this water is located in the Arctic, or drains out through northern rivers, and is, therefore, in practice unavailable for immediate use to most Canadians (except for that utilized by hydroelectric generation systems, discussed in Section 4.6). In practice, counting only the renewable supplies in southern Canada, where 85% of the population is located, Canada has about 2.6% of the world's supply, and this region of Canada is in fact significantly drier than the US average (Sprague, 2007; Schindler, 2007). Furthermore, Canada actually receives the same average amount of precipitation per square metre as do many other countries.

The reason why Canada seems to possess a wealth of freshwater is due to the fact that the Canadian landscape is marked by numerous depressions (created by several historical advancements and retreats of glaciers) that can hold water and form lakes, as well as on account of the relatively low degree of evaporation and transpiration in this colder region of the world. Thus, while Canada may have a fairly large 'bank account' of available freshwater, it has a very low 'interest rate' in terms of the capacity of its waters to replenish themselves – and if its expenditure of water exceeds the available 'interest', Canada will not be able to sustain its water 'capital' (Schindler, 2007). In fact, there currently exists a high threat to water availability in Alberta, Saskatchewan and Manitoba (Section 4.2), the Great Lakes region of south-western Ontario (Section 4.5), and regions dependent upon groundwater in many parts of Canada (Section 5.1). Moreover, the escalating oil sands developments in Alberta are increasing water demand and threatening water quality in that region (Section 4.3).

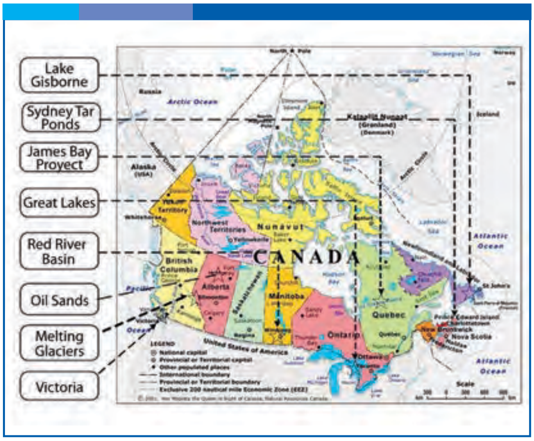

FIG .1. Map of Canada with Areas Discussed Indicated (NRCan, 2002)

FIG. 1 displays a map of Canada showing its political divisions along with many of its lakes and rivers, some of which are discussed later in this report. Labels circled on the left and linked to locations on the map are referred to in upcoming sections. The land area of Canada is approximately 10 million km^2, which makes Canada the second largest nation in the world next to the Russian Federation. As can be seen on this map, Northern Canada consists of Nunavut, the Northwest Territories, and the Yukon Territory. The southern part of Canada contains the ten provinces of Canada, most of which border the United States of America (USA). Going from west to east, these provinces comprise

British Columbia; Alberta, Saskatchewan and Manitoba (Prairie Provinces); Ontario; Quebec; and New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador (Atlantic Canada). Canada's industrial heartland is situated in Southern Ontario and Southern Quebec, while the "bread basket" of Canada is the Canadian Prairies where huge quantities of wheat and other grains are grown, in a region that often suffers from drought. Canada possesses huge reserves of a rich variety of natural resources located throughout the country including the massive oil sands of Alberta and Saskatchewan which require huge amounts of water to recover the hydrocarbon products as described later in Section 4.3.

As can be viewed in FIG. 1, the spatial distribution of the surface water is not equable across the country. The North and much of the Prairies are quite arid, with near-desert conditions in the high Arctic. The southern coastal areas, particularly along the Pacific Ocean, are very wet, while the regions bordering the St. Lawrence River and Great Lakes, much of the Atlantic Provinces, and the Rocky Mountains in the west enjoy ample, but not excessive, precipitation. Consequently, any consideration of water resources in Canada will often have a prominent regional dimension (CCA, 2009), as confirmed by the topics in Section 4.

Nearly 30% of Canada's population (almost ten million Canadians) depends on groundwater to supply its drinking water, and more than 80% of the country's rural population relies on groundwater for its entire water supply (Environment Canada, 2004). Although there is nothing in Canada to compare with the impending disaster of the Ogallala Aquifer in the USA — a vast groundwater reserve underlying the western Prairie states that will soon be "mined" to exhaustion (Reisner, 1993; de Villiers, 2003) — several serious problems with groundwater use have occurred or may be impending in Canada. Such water-related issues include the Walkerton tragedy in 2000, in which seven people died and more than 2,300 became seriously ill when a groundwater well was contaminated by E. coli bacteria in the town of Walkerton, Ontario due to water treatment mismanagement and inadequate regulation (Section 5.1); the more than 1,760 municipal and 93 First-Nations boil-water advisories in force across Canada (as of February 2008) (Eggertson, 2008), and actual or potential serious groundwater pollution problems associated with gas and oil development (Section 4.3), landfills, brownfields (Section 5.3), and industrial chemical spills and dumps. It is estimated that only about 3% of groundwater is active in the hydrological cycle (FIG. 3, Section 3.3) on an annual basis, and only 1% of the water in the Great Lakes is recycled annually. Exploitation of groundwater at a rate that exceeds these percentages is unsustainable in the long term. The CCA (2009) report states "Canada has not yet experienced widespread over-usage of groundwater. There have been individual cases where severe local problems have arisen, but this has not yet occurred on a national scale". Due to the great importance of groundwater in Canada, this topic is further investigated in Section 5.1.

In 1863, John Palliser described the Canadian Plains as "by no means a desirable district for settlement" with large areas that "will forever be comparatively useless". "By chance, the arrival of settlers to the prairies just over 100 years ago coincided with a shift to wetter climate conditions – a remarkable coincidence that allowed Canada's agricultural heartland to be developed. However, research on the Canadian prairies has shown that the region has experienced repeated and more prolonged droughts over the past few thousand years than those of the 20th century. Now with the development of large urban centres, extensive agriculture, and industrial growth, there is great consternation over water supply, particularly due to concerns over potential impacts of climate change on both water supply and demand." (Grasby, 2008) (Section 5.5).

Because of the immense importance of water resources in Canada as well as virtually every nation around the globe, the Academy of Science, within the Royal Society of Canada, hosted the conference entitled "Water in Canada and the World: Rising Tensions in the 21st Century: Issues and Solutions". This timely conference was held at the Canada Science and Technology Museum in Ottawa, Canada's capital city, on November 17th, 2006. The presentations and discussions at this conference, the viewpoints of researchers and practitioners throughout Canada, and the authors' expertise with respect to water, form the basis for much of the contents of this report regarding a strategic viewpoint of water resources in Canada. Research material from an ongoing sequence of conferences called International Conference on Environment and Water Research (ICWRER), first held at the University of Waterloo in 1993 with subsequent conferences held in Kyoto (1996), Brisbane (1999), Dresden (2002), Adelaide (2008) and Quebec City (2010), also furnished background information. Articles presented at the 2010 Annual Conference of the McGill Institute for the Study of Canada held at McGill University on March 25th and 26th on the topic of "Canadian Water: Towards a New Strategy," papers from annual conferences of the Canadian Water Resources Association, refereed articles from journals such as the Canadian Water Resource Journal, and information from valuable websites presented in Section 7, constitute other sources from which the authors obtained valuable background material.

As a result of Canada's sheer physical size containing many kinds of geographical regions and climate zones, some of Canada's strategic water problems are regional rather than being common difficulties occurring in many parts of the country. Accordingly, in Section 4 pressing regional water problems in Canada are addressed, starting in the west and moving eastwards. Within Section 5, the authors tackle water problems that affect many regions of the country. Most importantly, within Section 6, recommendations are put forward for enhancing water governance in Canada with respect to the regional and national water problems in Canada discussed in Sections 4 and 5, respectively, as well as other water issues not mentioned in these sections. Firstly, however, the current governance systems within Canada and its neighbour to the south are presented next.

3. Water Governance within Canada and Internationally

Canada requires a comprehensive national water policy, as pointed out in Section

3.1, although since its inception in 1867 Canada has made noteworthy advances in the management of its enormous water resources in cooperation with its provincial and territorial governments. Internationally, Canada and the USA cooperatively manage their many shared water basins in a fair and effective manner via the International Joint Commission which implements the policies of the Boundary Waters Treaty of 1909, as explained in Section 3.2. Water basins within Canada and those shared with its friendly southern neighbor along the border with the USA, are generally well-governed following the principles of integrative management under stakeholder participation (Section 6.2), as discussed in Sections 3.2 and 3.3, respectively. To overcome inherent weakness in federal water legislation regarding water quantity and quality issues, the Canadian Council of Ministers of the Environment tackles specific water and other environmental problems of national interest, as mentioned in Section 3.4. However, Canada's obligations to abide by the trade agreements within the World Trade Organization (WTO) and the North American Free Trade Agreement (NAFTA) threaten Canada's sovereignty over its natural resources, such as water and energy, and its environmental stewardship of its vast ecosystems as dictated in its national, provincial and local laws and regulations. The ongoing conflict over water and trade is outlined in Section 3.5 while the looming peril of the exportation of Canadian water in vast quantities is addressed in Section 4.7.

3.1 Legal Structure Water in Canada

The Dominion of Canada was created on July 1, 1867 and initially consisted of Ontario (Upper Canada), Quebec (Lower Canada), Nova Scotia and New Brunswick. Today, Canada consists of ten provinces, Nunavut, the Yukon and the Northwest Territories, as depicted in FIG. 1. The Constitution Act of 1867, formerly called the British North America Act, forms the foundations upon which the constitution has been expanded or modified on many occasions since the confederation of the four former British colonies to establish Canada. The Constitution Act specifies how responsibilities are shared among the three levels of government in Canada: federal, provincial or territorial and municipal. At the federal level, the Parliament of Canada consists of a House of Commons (Members of Parliament are elected. The leader of the political party holding the most seats is usually the Prime Minister) and a Senate (Senators are appointed). Under Article VI in the Constitution, Distribution of Legislative Powers, the federal government controls the regulation of trade and commerce (Section 91.2), navigation and shipping (Section 91.10), sea coast and inland fisheries (Section 91.12) and proprietary interest of certain northern waters (Shrybman, 2000).

Under Article VI in the Constitution Act, the provincial legislatures possess primary responsibility for most natural resources, public lands and property (Section 92.5). Although water is not explicitly mentioned in the Act, in law water is categorized as property and land is understood to include water. Accordingly, the provinces own their water resources, including both surface and groundwater, and are responsible for flow regulation, authorizing water use and development, as well as granting authority to legislate areas of water supply, pollution control, and thermal and hydroelectric power development. Additionally, the provinces have taken the primary responsibility for managing water via passing water laws, licensing water use and waste discharge, and delegating powers to local municipalities and basin conservation authorities which carry out important implementation roles in water management. Nonetheless, the division between federal and provincial jurisdictions is not always clear, or is contradictory, as in the case of water exports discussed in Section 4.7. An additional legal complication within Canada is that water law in Quebec is derived from Quebec Civil Code, which has its roots in Code Napoleon, whereas water laws in other Canadian provinces fall within civil law based upon Common Law from the United Kingdom.

Because water often crosses or overlaps with jurisdictional boundaries within Canada and also with the United States, the federal government is often involved with intergovernmental accommodation and cooperation (Pearse, 1998). After confederation in 1867, the federal government assumed responsibility for key water projects, such as large dams and flood control works, and for serving the nation's interests, like encouraging commerce and settling the west (Sections 3.2. and 3.3 for the case of bilateral cooperation with the United States). In 1966, a water administration was established in the new Department of Energy, Mines and Resources, for which the freshwater component later became the Inland Waters Directorate. Subsequently, an Interdepartmental Committee on Water was founded to coordinate water programs, and legislation passed in 1970 included the Canada Water Act, Arctic Water Pollution Act, Northern Inland Water Act and amendments to the Canada Shipping Act and Fisheries Act. Canadians were clearly concerned with many issues related to water such as water supply, spread of water contaminants, pollution control, flood damage reduction, drought and heritage river protection. They came to envision water as not just a commodity but as a fundamental element of the environment and Canadian culture.

The federal government's contributions to water policy reached its apex in 1987, with the issuance of the Federal Water Policy, which was based on the 1985 Pearce report. This relatively insightful and encompassing policy was designed "... to encourage the use of freshwater in an efficient and equitable manner consistent with the social, economic and environmental needs of present and future generations". Unfortunately, the Federal Water Policy was tabled in the House of Commons and never became law. Instead, issues related to water were absorbed within the Canada Environment Act of 1989, and the ruling Conservative government focused on negotiating the 1989 Canada-USA Free Trade Agreement. Currently, Canada still does not possess an encompassing national water act and a key recommendation in Section 6.1 is that Canada develop one.

Under the existing Environmental Protection Act, the Fisheries Act and the Canada Water Act, the federal government has overriding responsibility for the health of inland fisheries, the transmission and deposition of deleterious substances and the mandate to monitor the status of the nation's freshwater. The federal government also oversees transboundary waters, water for aboriginal communities, and water on federal lands such as national parks and Department of National Defence lands.

Federally-supported research studies are continuing. In 2004 Environment Canada published a collection of studies of municipal, agricultural and industrial uses of water (Environment Canada, 2004), and in 2009 an Expert Panel of the Council of Canadian Academies published their study on groundwater in Canada (CCA, 2009) (Section 5.1).

3.2 Boundary Waters Treaty of 1909

Globally, there are 261 international river basins draining a total area equal to half of the land mass in the world (Wolf, 2010) and about 40% of the world's populations live in water basins shared by two or more nations (Global Water Partnership, 2009, p. 55). Many people believe that nations competing for control of scarce water resources may ignite warfare among countries in the future (Gleick, 1993), although some authors think that conflict over water may be a reason for cooperation and peace (Wolf, 2002). Accordingly, to protect and conserve limited water resources and to avoid possible international conflict over transboundary water resources, an increasing number of international water policies are being put into effect (Dellapenna, 2001). Currently, over 3,600 bilateral and multilateral international agreements have been signed around the globe (Vinogradov et al., 2003), of which four important treaties are compared by Ma et al. (2007) to assess their effectiveness according to meaningful criteria. The first general codification of the laws pertaining to international watercourses was the Helsinki Rules on the Uses of the Waters of International Rivers, which was adopted by the International Law Association in 1966. Although the Helsinki Rules guideline was not legally binding, it soon received global acceptance as customary international law and was an important influence on the water agreements of many organizations and countries until the creation of the United Nations' Convention on the Law of Non-Navigational Uses of International Watercourses in 1997. It was superseded by the Berlin Rules on Water Resources in 2004 (Salmon, 2007).

On January 11, 1909, the USA and Great Britain, on behalf of the Dominion of Canada, signed the Boundary Waters Treaty, which has proven to be over time a highly successful bilateral treaty to prevent and resolve transboundary disputes regarding water and the environment and, therefore, provides an ideal model for countries to emulate. FIG. 2, displays the many water basins overlapping the Canada/USA border, spanning almost 9,000 km. The fundamental reason why this treaty has worked so well in resolving conflicts arising in the numerous international river basins shared by these two nations is that the treaty has been purposefully designed to reflect the values of the stakeholders in a fair and transparent way by "hard-wiring" appropriate provisions into the treaty. Specifically, to implement its mandates and to make it fully operational, the treaty created the International Joint Commission (IJC), an independent binational body having investigative, regulatory and adjudicative roles. The IJC is comprised of six members – three Commissioners appointed by the President of the United States, with advice and approval of the Senate and an opportunity for congressional oversight of the appointment, and three by the Governor in Council of Canada, with input from the Prime Minister but no additional oversight. Accordingly, the citizens of both countries have equal representation on the IJC, with a Commissioner from each country serving concurrently as co-chairs. Most importantly, the six Commissioners must act impartially in reviewing problems and deciding on issues, rather than representing the views of their respective governments. In other words, the IJC does what is best overall for the citizens of both countries, rather than acting in the interests of corporations, which is the case for the North American Free Trade Agreement discussed in Section 3.5. As a dispute resolution mechanism, the IJC seeks win/win resolutions. The IJC can make recommendations on an issue or reference put forward by either country, although in practice it only acts when both countries request an investigation.

When investigating a problem, such as the proposed Garrison Diversion Unit irrigation project mentioned in Section 4.4 (IJC, 1977) and the fluctuating water levels of the Great Lakes (Levels Reference Study Board, 1993; Yin et al., 1999; Rajabi et al., 2001; IJC, 2009a) (Section 4.5), the IJC calls upon the best experts from both countries to carry out extensive background studies to come up with impartial recommendations for settling the dispute. Since its inception, the IJC has executed numerous reference studies, including one dealing with water exports (IJC, 2000) (Section 4.7) and another addressing the management of international basins following an integrative and adaptive approach (IJC, 2009b) (Section 6.2). In its regulatory capacity, the IJC gives approval for the construction and operation of water works that may affect the levels or flows at the international boundary. Over its history, the IJC has established 30 boards, task forces and study boards to manage transboundary waters such as the Great Lakes Water Quality Board discussed in Section 4.5.

FIG. 2. Water Basins Overlapping Canada/USA Border (Environment Canada, 2011)

Two Canadian provinces (Ontario and Quebec) along with eight American states share the Great Lakes Basin. In December 2005, these political entities signed the Great Lakes Charter Annex Agreement, which considerably strengthens conservation measures, and provides stronger protection against proposals for water diversions from the Great Lakes Basin. This agreement and other related versions thereof are discussed in the introduction to Section 4 and in Section 4.5.

3.3 Water Governance at the Basin Level

The continuous movement of water in all of its forms in the atmosphere, on the surface of the land and underground is referred to as the hydrological or water cycle. The systems diagram of the hydrological cycle depicted in FIG. 3, was first envisioned during the Renaissance by Leonardo da Vinci and constitutes the first accurate description of a key environmental system (Hipel and McLeod, 1994, and references contained therein). When precipitation falls on a land surface, water on or near the surface naturally follows the contours of the land to flow downhill first as small streams, which in turn amalgamate to create larger rivers and lakes. A river basin or watershed, which can consist of one or more smaller basins, forms an important component of the overall hydrological cycle drawn in FIG. 3 and, therefore, provides a natural geographical unit within which water governance can be effectively implemented for managing both water quantity and quality issues (Bruce and Mitchell, 1995). An integrative and adaptive approach to water governance within a system of systems framework is presented in Section 6.2.

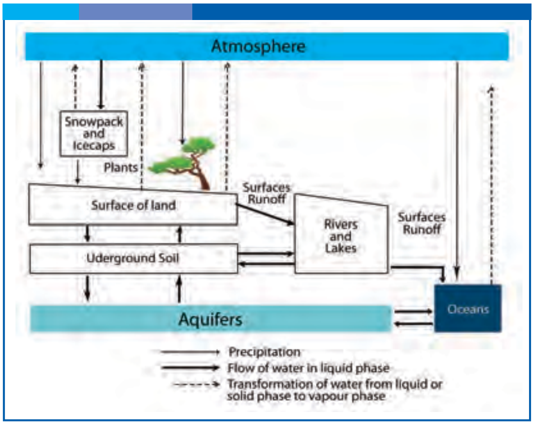

FIG. 3. Hydrological Cycle (Eagleson, 1970; Hipel and McLeod, 1993)

Fortunately, governmental bodies across Canada now recognize the importance of having water governance at the basin level, even if a basin crosses international boundaries as shown in FIG. 2 for the case of Canada and the United States, or intersects with jurisdictional boundaries at the provincial or lower levels. In Canada, the first watershed management agency was the Grand River Conservation Commission which was established by an act of the Provincial Government of Ontario in 1932 to address flooding, drought and pollution problems caused by land-use changes made in the highly-developed Grand River Basin of Southern Ontario depicted in FIG. 4. The success of the Commission led to the passing of the Conservation Authorities Act of Ontario in 1946, and the creation of 36 conservation authorities in Ontario within which all of its 12 million citizens live. The original Grand River Conservation Commission has evolved into what became the Grand River Conservation Authority (GRCA) in 1966. In fact, the GRCA has been so successful in executing its mandate that in 1994 the Grand River, which flows about 300 km from the highlands of Dufferin County in the north of the basin to Lake Erie in the south, was classified as a Canadian Heritage River. In 2000, the GRCA was awarded the International Riverprize in Brisbane, Australia, for excellence in river management.

Enlightened governance is a direct result of sound design. In particular, the Conservation Authorities Act contains three fundamental concepts to bring about desired performance of a given Conservation Authority for managing a river basin. Firstly, a Conservation Authority is a local initiative since residents must request the Ontario government to form an Authority under the act, share in its financing and assume the responsibility of running it, similar to what is done for a municipality. In this way, citizens living in the watershed are empowered as stakeholders through the Authority to undertake projects involving water which they can handle economically, culturally and democratically.

Length: 280 km
Area: 6,800 km²
Elevation change: 351 m
Average monthly precipitation range (across 7 GRCA operated climate stations): 70.1 mm – 80.0 mm

Location	Mean Annual Flow (m^3/s) (for 2009)
Dundalk (source)	1.19
Marsville	9.0
Shand Dam	11.4
West Montrose	17.1
Doon	32.5
Galt	48.7
Brantford	95.5

SOURCE: GRCA,2001,2010,2011: ENVIRONMENT CANADA, 2010

FIG. 4. Grand River Basin in Southern Ontario, Canada (GRCA, 2001, 2010, 2011; Environment Canada, 2010)

Secondly, the costs of projects are shared by municipalities and the provincial government which means that an Authority will only succeed when the local residents are willing to support it financially. Thirdly, a conservation authority possesses watershed jurisdiction over the one or more river basins under its control, which gives it the ability to handle problems such as flood control, reforestation, low flow augmentation, recreation and other responsibilities it chooses to undertake in a responsible, rational and systematic manner.
Besides Ontario, other provinces have implemented innovative water governance at the water basin level. For instance, as is also pointed out in Section 6.1, Quebec established effective watershed-based management throughout the province via the Quebec Water Policy of 2002 (Government of Quebec, 2002). The foregoing type of insightful water governance within a watershed stands in sharp contrast to the lack of leadership at the national level in terms of having a proper national water policy. This lack of national guidance may be partially due to the fact that the power to manage water resources rests largely with the provinces except at international boundaries

(Section 3.2), in aboriginal communities, and on federal properties (Section 3.). In lieu of this, the provinces have put together a mechanism for cooperating on addressing specific environmental issues as described in the next subsection.

3.4 Canadian Council of Ministers of the Environment

As explained in Section 3.1, the Canadian federation-based government system places control over natural resources such as water under the shared jurisdiction of both provincial and federal governments. The exceptions where federal jurisdiction prevails include waters crossing international boundaries (Section 3.2), water on federal properties and First Nations' lands, and where water flows between two or more provinces. Partially as the result of a lack of a national water policy, the Canadian Council of Ministers of the Environment (CCME) was formed to tackle environmental problems of national concern such as those involving water. The membership of the CCME consists of the 14 environment ministers from the federal, provincial and territorial governments, who meet at least once per year to confer over environmental priorities for Canada and decide upon tasks to be executed under the auspices of CCME.

When the Environmental Ministers select a specific environmental issue to address, senior officials establish working groups of experts from the federal, provincial and territorial ministries to accomplish the required tasks with the support of a permanent secretariat. When needed, expertise from elsewhere, such as academia and the private sector, will be sought via the formation of an advisory committee. Examples of work completed by CCME are the Canada-Wide Acid Rain Strategy, from a broad perspective, and the Code of Practice for Petroleum Storages Tanks, for a specific technical problem.

As an illustrative example of a problem addressed by the CCME, consider the lack of consistency with respect to wastewater effluent quality between provinces which can result in conflict. In an effort to harmonize policy in this area, on February 17, 2009, 13 of the 14 governments agreed on the "Canada-wide Strategy for the Management of Municipal Wastewater Effluent", which sets National Performance Standards (CCME, 2009). (Note: Quebec has not endorsed the Accord or the Canada-wide environmental standards.) The objectives of the harmonization process are the delivery of a regulatory strategy that enhances public and environmental health protection, promotes sustainable development and achieves better overall management of municipal wastewater. The Accord also has the objective of preventing overlapping of activities and inter-jurisdictional disputes; reviewing and adjusting management regimes to accommodate needs; delineating the roles of governmental units; and developing consistent approaches on issues. A total of 13 principles were defined to ensure a more consistent approach to effluent management by all jurisdictions.

The initial Performance Standards specify maximum values for carbonaceous biochemical oxygen demand using the five day test (cBOD5) of 25 mg/L, total suspended solids (TSS) of 25 mg/L and total residual chlorine (TRC) of 0.02 mg/L. In addition, the effluent should not be toxic. Although these values do not represent the performance expected from state of the practice and do not even approach the state of the art, they represent a substantial step in the process of harmonization of national, provincial and territorial activities in pollution reduction. In fact, a more concentrated effort has been made in the Province of Alberta towards the development of a regulatory framework for managing cumulative environmental effects (Alberta Environment, 2007). Recognizing that all activities in every watershed impact in some fashion the quality of the environment and particularly the water, it is imperative that the cumulative impacts become a focus of management efforts. Achieving working relationships among all users in a watershed can be a formidable but necessary task.

3.5 Conflict over Water and Trade

As explained below, Canada's international trade takes place within the umbrella of agreements falling under two major, and closely connected, sets of agreements: the array of agreements sponsored by the World Trade Organization (WTO) and the North American Free Trade Agreement (NAFTA). Unfortunately, Canada's valuable water resources are not protected under WTO agreements or NAFTA, as was falsely claimed by the initial proponents of NAFTA. In reality, these two collections of trade agreements deal solely with bottom-line economics and so-called fair trade issues with little regard for environmental conditions, human rights, labor laws and other societal considerations. Moreover, given the fact that ecosystems are in rapid decline around the globe and the climate is warming as a direct result of industrial, agricultural and other human activities connected to trade, these trading agreements clearly have to be replaced or radically updated to respond to the massive environmental crisis facing humanity, including problems associated with the decreasing quantity and quality of fresh water. A recommendation regarding trade agreements is put forward in Section 6.3.1 because of the close connection between water and trade. In fact, as mentioned earlier in Section 3.2, as water becomes scarcer in a world still undergoing huge population expansions, many authors predict that there will be water wars (Dyer, 2008), although Wolf (2002) believes that water forms a focus for cooperation between nations and cultural groups. Whatever the case, the increasing relative scarcity of fresh water is bound to breed more and more conflict which hopefully will be resolved in a cooperative fashion rather than by outright hostility. Nonetheless, if responsible action is not taken soon, trade and the environment are on a collision course (Hipel and Obeidi, 2005).

Since the end of World War II, great strides have been taken to encourage free trade among nations according to fair trading rules within a global marketplace. The General Agreement on Tariffs and Trade (GATT) was established in 1947, and has been subsequently amended by several agreements. GATT was established as part of the post-war Bretton Woods Agreements that also created the World Bank and the International Monetary Fund. As the finale of the Uruguay Round of Negotiations, which started in September 1986, the Marrakesh Agreement was signed in Morocco in April 1994 to establish the

World Trade Organization (WTO), which officially came into operation on January 1, 1995. The WTO has a range of agreements, including the latest version of GATT and a dispute resolution procedure, to encourage free trade around the globe.

The North American Free Trade Agreement among Canada, Mexico and the USA came into operation on January 1, 1994, and constitutes an expansion of the earlier Canada-USA Free Trade Agreement of 1988. One of the supplements to NAFTA is the North American Agreement on Environmental Cooperation (NAAEC) which, unfortunately, only obligates the three countries to enforce their own environmental laws rather than having strict environmental regulations across nations as is done in Europe. Currently, countries of North and South America are putting together an agreement called Free Trade Area of the Americas (FTAA), which is planned to eventually replace NAFTA. Another organization that deals solely with trade issues from the perspective of big business is the Security and Prosperity Partnership (SPP) of North America which was signed on March 23, 2005 by the leaders of Canada, Mexico and the USA. In fact, the SPP was initiated by the Canadian Council of Chief Executives which feared border disruptions with the USA because of its War on Terror.

NAFTA and the economic agreements falling under the WTO are fully operational and are largely being adhered to by member states. Unfortunately, this is not the situation with regards to transnational environmental treaties and at the present time no really comprehensive and binding international agreement on the environment or water is in place. However, a few successful treaties regarding the environment have been accomplished in specific areas, including the Law of the Sea (Division of Ocean Affairs, 1997) and the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer (UNEP, 2003). As explained in Section 3.2, within North America, the Boundary Waters Treaty of 1909 between Canada and the USA constitutes an exemplary and long-tested illustration of a successful bilateral treaty which deals with water quantity and quality problems as well as air pollution. Nevertheless, most global environmental initiatives have not materialized at the international level: the nations of the world did not adhere to the Kyoto Protocol for reducing greenhouse gasses and did not develop a program for reducing emissions at the Copenhagen meeting of December, 2009. Although Canada currently does not have a national water policy (Section 3.1), it is attempting to have some national consistency in its environmental standards via the Canadian Council of Ministers of the Environment (Section 3.4).

A major problem with international economic agreements is that the underlying value system or objectives written into these treaties may be in direct conflict with the value systems of environmental and water laws in Canada and most other nations. Consider, for instance, the case with respect to NAFTA. Under Chapter 11, corporations or individuals can sue Canada, Mexico or the USA for compensation when actions taken by those governments adversely affect their investments. Hence, as explained in Section

4.7, an American company is suing the Canadian government for not permitting it to export water in bulk quantities, as was earlier permitted by a provincial government before revoking the company's license, even though large-scale removal of water could cause serious ecological damage.

Accordingly, opponents of NAFTA argue that this international agreement permits corporations to override Canadian federal and provincial environmental, social, cultural and economic laws, and thereby pose a threat to Canada's sovereignty and the rights of individual Canadians. McMurty (2002, pp. 112-113) points out that the WTO agreements and NAFTA have binding regulations on the rights of transnational investors and corporations but there is not a single binding article with respect to the protection of the environment, human rights and labour. Hipel and Obeidi (2005) explain the value systems of the proponents of free trade and those of environmental stewardship in the ongoing conflict over trade versus the environment and provide numerous references presenting the positions taken by both sides. Moreover, according to the proportionality principle in NAFTA, once water exports are permitted they cannot be stopped since the country supplying the water cannot reduce the relative quantity of water exported to the receiving country. As mentioned in Section 4.7, in response to public outcry in the USA and Canada over proposed bulk water exports, the International Joint Commission (Section 3.2) recommended in a 2000 study that no boundary waters be exported in bulk unless it can be definitely proven that the ecology will not be harmed (IJC, 2000). Nonetheless, if a case over water exports were taken to the international court in The Hague, it is not clear which side would win. Other concerns over the exploitation of water are furnished by authors such as Sandford (2009), Barlow (2007), Barlow and Clarke (2002), de Villiers (2003), Dellapenna (2001) and Wolf (1998). Canadian and European officials are negotiating a new trade agreement, called the Canada-European Union Comprehensive Economic and Trade Agreement (CETA). Similar to NAFTA, CETA would give the interests of European corporations precedence over the rules and standards of Canadian provinces and municipalities (Barlow, 2011). This would potentially have many serious consequences for Canada, including the privatization of its public water systems (Canadian Union of Public Employees and Council of Canadians, 2010).

Because current international economic agreements only deal with the economic aspects of trade among nations, the integrity of both the quantity and quality of water in Canada's river basins are under constant threat, even though responsible water governance may be taking place at the basin level (Section 3.3) and other jurisdictions within Canada (Sections 3.1 and 3.4), as well as river basins straddling the border between Canada and the United States (Section 3.2). With respect to the systems diagram called the hydrologic cycle in FIG. 3, this means that Canada's water resources could be damaged at the basin level if appropriate legal protection is not provided. Additionally, climate change, which many scientists believe to be exacerbated by the continuing release of enormous amounts of greenhouse gases due to the widespread utilization of hydrocarbons as the key energy provider for the ever-expanding economic engine, can affect all parts of the hydrological cycle. Therefore, three recommendations are put forward in Section 6.3.2: one encourages Canada to negotiate an international economic agreement that prioritizes the maintenance of a healthy environment, societal welfare and the rights of individuals within a sustainable development structure; another proposes that Canada negotiate an effective greenhouse gas emissions treaty to lessen the likelihood that the entire hydrological cycle in FIG. 3 becomes severely and irreversibly damaged due to global warming and climate change (see comments under Recommendation 9 in Section 6.3.2), and a third suggests that Canada participate in drawing up a comprehensive international treaty for freshwater.

4. Strategic Regional Water Problems in Canada

As explained in Section 1 and shown in the map of Canada in FIG. 1, Canada is the second largest nation in the world with a surface area of ten million square kilometers spanning many climate and geological regions as well as containing a rich range of ecosystems. Accordingly, many of Canada's strategic water problems are contained within specific regions in Canada. Going from west to east, particular water problems in Canada start with the melting glaciers of the Rocky Mountains of Western Canada discussed in Section 4.1. The melting of these glaciers is exacerbating drought conditions in the Prairie Provinces (FIG. 5), as mentioned in Section 4.2. A further drain of water resources in Alberta and somewhat in Saskatchewan is the quickly increasing demand for water needed for extracting and processing bitumen mined from the vast oil sands reserves (FIG. 6), as explained in Section 4.3. A new threat to surface water supplies is the emerging shale gas industry, which is already leading to significant water withdrawals from river systems in the Horn River Basin of northeastern British Columbia. Current water withdrawal licenses there permit removal of water in volumes up to 275,000 m^3 (Parfitt, 2010, p. 26). This industry also has implications for groundwater use, as discussed in Section 5.1.

The Red River Basin of Manitoba and North Dakota (FIG. 9), as well as downstream lakes and rivers like Lake Winnipeg, are under direct threat of projects in the USA such as intense agricultural activities and the draining of the highly polluted inland lake, called Devils Lake in North Dakota, which empties via the Sheyenne River into the Red River which flows northwards into Canada. A nasty brew of pollutants and foreign biota from North Dakota could have devastating environmental consequences in Canada, as discussed in Section 4.4, while spring flooding in the Red River Basin will continue to wreak havoc (FIG. 10.), as has recently happened in 1997, 2009 and 2011. Fortunately, the City of Winnipeg has constructed a highly effective floodway system for channeling floodwaters from the Red River and its tributaries around the city (FIG. 10), but other areas can be flooded.

The governance of the Great Lakes (FIG. 11), addressed in Section 4.5 in terms of both water quality and fluctuating lake levels is well executed as a direct result of the outstanding policies of the International Joint Commission (Section 3.2) as well as the eight American states and two Canadian provinces with which the Great Lakes Basin overlaps.

Although hydroelectric power is generated from differences in elevation at many lakes and rivers across Canada, the massive James Bay project of northern Quebec (FIG. 12) and the Churchill Falls in Labrador are particularly noteworthy. The conflict over these projects with First Nations peoples as well as the dispute between the government of Quebec and the government of Labrador and Newfoundland over the sale of Churchill power to Quebec Hydro at an extremely low rate are discussed in Section 4.6. Finally, the ongoing debate over the potential sale of Canadian water in bulk quantities is put into perspective in Section 4.7.

People living in the dry areas of the southwest USA and other arid regions of the world have speculated about importing enormous quantities water from Canada (FIG. 1), especially from what is incorrectly perceived to be infinite reserves of fresh water from the Great Lakes (FIG. 11). In fact, large quantities of water are already being exported within and outside of Canada as bottled and virtual water, as explained in Section 5.4. It was an awareness of the potential threats to the Great Lakes from drier areas of the continent that led to the signing of the Charter Annex Agreement in 2005, as noted at the end of Section 3.1.

4.1 Melting Glaciers

The amount of glacial ice in Canada is surpassed only by that of Antarctica and Greenland (CCME, 2010). Around 200,000 km^2, or 2%, of Canada's surface area is covered by glaciers and icefields (NRCan, 2009), which comprise the equivalent amount of water of all the lakes and rivers in the country (NRCan, 2010). These glaciers and icefields are situated in the Western Cordillera region, which stretches across British Columbia and the western edge of Alberta, and in the eastern Arctic. The importance of glaciers for water is that they act as natural water towers, storing up water in the form of ice during winter and then releasing it as the ice is melted by the sun's heat, thus supplementing river flows throughout the summer months (NRCan, 2001). These rivers are relied upon for such applications as municipal water supplies, irrigation, hydroelectric power generation and fisheries (CCME, 2010). The loss of glacial ice is thus an important water resource issue for Canada. As the availability of water is of special concern for the relatively dry Prairie Provinces (Alberta, Saskatchewan and Manitoba) (Section 4.2) this section focuses on the effect of glacial decline on the Prairies.

Most of the world's alpine glaciers are in retreat. There was a 12% decrease in glacier size worldwide during the twentieth century, according to the World Resources Institute (CCME, 2010). Studies show that this trend started about 1800 AD, although some Swiss glaciers went on expanding until about 1860. The retreat is usually attributed to global warming, but it should be noted that glaciers have demonstrated a complex history of advance and retreat since the last Ice Age. The evidence indicates that alpine ice was entirely absent during the post-glacial Holocene maximum, from about 7,000 to 4,000 years ago, with forest cover extending to at least

2,600 m above sea level. The current phase of retreat follows a brief period of glacial advance during the "Little Ice Age" that peaked in the mid-seventeenth century (Rutter et al., 2006). There are over 1300 glaciers along the eastern slopes of the Canadian Rocky Mountains, which stretch across and beyond the western edge of the Prairie Provinces (FIG. 5, Section 4.2) and along the eastern side of British Columbia. These glaciers are a key source of water for rivers in the Prairie Provinces, discharging millions of cubic metres of water eastward across the Prairies (CBC News, 2003). The snow pack in the Rocky Mountains performs a similar function to glaciers, building up over the winter and then releasing water to rivers as it is melted by warmer weather, providing most of the streamflow runoff (Lapp et al., 2005).

As demonstrated by Schindler and Donahue (2006), however, the diminishing alpine snow pack in the Rocky Mountains means the spring melt tapers off into the summer, delivering less water to the Prairies during the late summer. Leung and Ghan (1999) predict an average snow cover reduction in this region of up to 50% in the event of a doubling of atmospheric CO2 levels. Currently, glacial melt continues to deliver water to Prairie river systems throughout the summer but this resource is now shrinking rapidly. These glaciers have diminished by 25 to 75% since 1850 (CCME, 2010) and are approaching the lowest levels they have been in 10,000 years (NRCan, 2007). Although the shrinking of the higher elevation icefields may be offset by increased snowfall according to certain climate models, the lower lying glaciers are expected to continue declining rapidly (Parks Canada, 2003).

The Bow Glacier in Banff National Park, Alberta, is an important glacier in the Rocky Mountains that is shrinking at a rapid rate. During summer months, this glacier is a significant water source for the Bow River, which supplies the City of Calgary's drinking water. The Bow Glacier has been reduced by 27% within the past 60 years and it could vanish entirely in 40 years (Ma, 2006). Another significant glacier in Banff National Park that is endangered is the Peyto Glacier. Researchers began measuring this glacier in the early 1980s and found 20 years later that it had lost 70% of its mass, its height having been reduced by the equivalent of a five-storey building. They also discovered that its rate of melting is increasing (CBC News, 2003). On account of the shrinking of Rocky Mountains glaciers such as these ones, river flows in the Prairies have been reduced by as much as 25% (CBC News, 2003). The diminishment of the Rocky Mountains snow packs and glaciers, however, is not as severe a problem as it could be, as dams have been constructed that can hold a great deal of springtime flow and gradually release it as needed through the summer.

The disappearance of glaciers is also a major concern for British Columbia. Most of the glaciers in the southern region of the province have diminished considerably since the 1920s, although glaciers in the north-west have expanded on account of heavy snowfall (Bruce et al., 2000). A climate change expert in British Columbia has predicted that the majority of the glaciers within that province will be lost within 150 years (Lupick, 2008). Another study determined that glaciers in the northern hemisphere would undergo a 60% overall reduction in volume if average global temperature increases by 3°C (Canadian Geographic, 2010a). When Western Canada's glaciers disappear, it will be faced with a major water crisis (Ma, 2006), especially the Prairie Provinces, as explained in the next section

4.2 Droughts in the Prairie Provinces

As shown in FIG. 5, Canada's Prairie Provinces, consisting of Alberta, Saskatchewan and Manitoba, have major rivers originating in the Rocky Mountains which flow across them. In the southern part, the North and South Saskatchewan Rivers drain from west to east to the middle part of the Province of Saskatchewan where they join together and flow as a single river to Lake Winnipeg.

Further north, the Peace River and Athabasca River also start in the Rocky Mountains but flow northwards and eventually empty into the Arctic Ocean via the Mackenzie River. Human modifications to river basins, possibly in combination with climate warming, have already changed the timing of the flows of major rivers in the Prairie Provinces, especially during the summer months from May to August when water demand is high (Schindler and Donahue, 2006). In-stream flows requirements are still met by the current runoff. About half of the ten key sites that were examined by Schindler and Donahue (2006) currently receive 14 to 24% less precipitation than at the commencement of the period of record and none of the locations have experienced precipitation increases.

However, most seriously, Schindler and Donahue (2006) note that summer flows have been reduced by 20 to 84% when compared to the early 20th century, with peak runoff occurring increasingly earlier as the winter snowpacks are reduced and glaciers retreat in the Rocky Mountains (Section 4.1) in conjunction with increasing temperature. The worst affected river is the South Saskatchewan River, for which the summer flows have decreased by 84% over the past century and its main tributaries (the Oldman, Bow and Red Deer Rivers) have been subjected to impoundments and winter flows have been substantially increased to protect the aquatic environment. As droughts and water shortages increase in the Prairie Provinces, and perhaps other areas of Canada, the nation clearly needs insightful governance for fairly allocating water among competing users, perhaps following the systems approach proposed by Wang et al. (2008), who have applied their methodology to the South Saskatchewan River Basin in Alberta and the Aral Sea in Central Asia. Accordingly, a specific recommendation is put forward in Section 6.3.1.

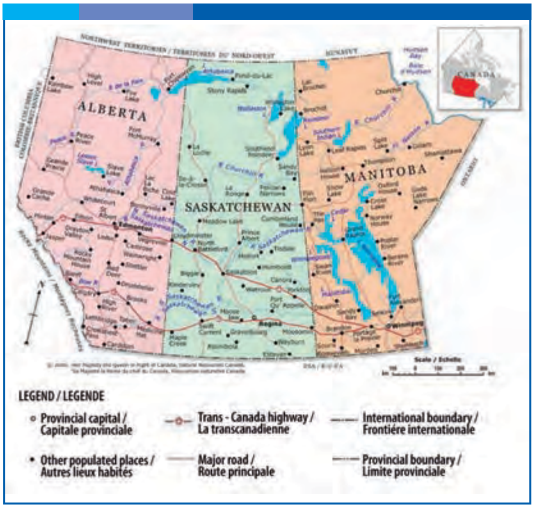

FIG. 5. Prairie Provinces of Canada (NRCan, 2003)

Climate models predict an additional warming of several degrees for the Prairie Provinces later in the 21st century (Canadian Institute for Climate Studies Project, University of Victoria). In addition, the forecasted warming could significantly increase evaporation by up to 55% in some locations. Although climate models also predict slight precipitation increases, these increments are much lower than the expected increases in evapotranspiration. What is interesting to note is the Prairie Provinces will become much drier in the future even if the precipitation increases. Moreover, as discussed in Section 4.1, glacial wasting in the Eastern Rocky Mountains has advanced far enough that glacial melt is decreasing which in turn decreases the summer flows of the main Prairie rivers. Unfortunately, drought in the Prairies will be further exacerbated as the human population continues to increase, agricultural activities expand, wetlands continue to disappear, and increased extraction of oil from the oil sands require more water if improved technologies currently available are not implemented (Section 4.3).

The predictions referred to in the previous paragraphs rely upon climate and hydrology modeling as well as extensive statistical analyses in the face of high uncertainty, all of which depend upon having a reliable data base and extensive monitoring. Therefore, it is not surprising that there is not universal agreement about the causes or seriousness of these predictions (Grasby, 2008). Environment Canada (2004) data show that drought in Western Canada and in the Great Lakes region has been cyclical over decadal periods. Chen and Grasby (2009) argue that most climate and discharge records are too short to permit the extraction of long-term trends that might isolate the effects of recent global warming from regional climatic shifts attributable to ENSO (El Niño-Southern Oscillation) and other natural decadal phenomena. Whatever the case, all of this work depends upon having sufficient and reliable data and, therefore, a recommendation is put forward in Section 6.3.1 to enhance and expand the monitoring of Canada's water resources so that informed decisions can be made. Shortages of water in the Prairie Provinces aggravate water quality problems. Massive land use changes, destruction of wetlands and riparian areas, larger discharges of treated human and animal wastes, increased usage of fertilizers and pesticides, and expansion of activities in the oil and gas industries as well as other industrial undertakings, all contribute to the increased introduction of nutrients into the receiving bodies of water. This will cause water quality problems such as increased eutrophication, more risk of infection by waterborne pathogens and declining sports fisheries if currently recognized treatment technologies are not instituted.

4.3 The Oil Sands

Of the many non-agricultural industrial uses of water, three have dominated the uses in Canada: pulp mill operations, a variety of mining operations, and the oil and gas industries. These are primarily raw material extraction and export industries for Canada with only limited value-added components. Water use is variable in these industries. In the pulp mill operations, most if not all of the mills have secondary wastewater treatment in operation. In the mining industries, operational protocols commonly led to finding alternative water use options and water treatment or storage. The oil industry, particularly the oil sands developments of Alberta, has received a great deal of attention because of the enormity of the reserves, the increased pace of expanding oil sands projects, a range of environmental problems including both water quantity and quality issues, and fairness issues over how the wealth is shared among the stakeholders. The oil sands, which are also referred to as the tar sands, are viscous mixtures composed of inorganic materials, bitumen, silt, clay, and water, along with a small portion of other materials such as titanium, zirconium, tourmaline, and pyrite.

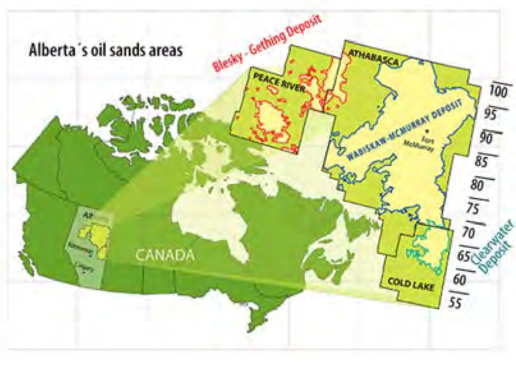

FIG. 6. Oil Sands Areas (ERCB, 2009)

The bitumen is a viscous, heavy crude oil-based material which is extracted from the oil sands and subsequently upgraded into a range of oil products. As shown in FIG. 6, a great deal of Canada's oil sands is situated at three main locations in the Province of Alberta: Athabasca, Cold Lake and Peace River, whose total area is 140,200 km^2, which is about the same size as the USA state of Florida. These three areas are located in the Mackenzie River Basin, a vast and crucial ecosystem comprising 1.8 million km^2, or 20%, of Canada's total land area (de Loë, 2010). Canada's total estimated oil reserves of 178 billion barrels, of which 173 are contained in the oil sands, make Canada the world's second largest oil nation after Saudi Arabia which has reserves of 267 billion barrels (US Energy Information Administration, July 2010). Two main approaches are utilized to recover bitumen in the oil sands: surface, or open-pit, mining and in-situ technologies. Twenty percent of the oil sands are recoverable via surface mining, while 80 percent are recoverable via in-situ methods (CAPP, 2011). When the oil sands are situated within 75 meters of the surface, huge shovels are used to dig up the ground on the surface of the land for loading into large dump trucks for transportation to a crusher and cyclofeeder. The oil sands are mixed with a diluent to form a slurry for hydrotransport via pipelines or trucks to an extraction facility where the bitumen is separated from the oil sands through a water-based extraction process. Utilization of this technology results in 90 percent of the bitumen being recovered.

Unlike surface mining, the in-situ approach does not leave large pits on the landscape and is used for recovering bitumen from deeply-buried oil sands deposits. The basic idea behind the range of in-situ mechanisms is to employ a specific procedure for forcing bitumen to the surface for collection and transportation to processing facilities. Four key in-situ technologies are the Cyclic Steam Stimulator (CSS), Steam-Assisted Gravity Drainage (SAGD), Vapor Extraction (VAPEX), and Toe-to-Heel-Air-Injection (THAI) methods. For CSS and SAGD, steam is injected through pipes into the oil sands reservoir to heat the bitumen. The lowering of the viscosity of the bitumen permits it to flow like conventional oil such that the heated oil and water can be pumped to the surface. Approximately 20 to 25% and up to 60% of the bitumen is recovered using the CSS and SAGD procedures, respectively. Because SAGD is more efficient in terms of a lower steam-to-oil ratio (SOR), it requires less natural gas than CSS for producing the steam (National Energy Board, 2004).

When using VAPEX, vaporized solvents, such as propane and butane, are injected into the reservoir in order to cause the bitumen to move towards the production well. Since a vaporized solvent is used instead of steam, water is not needed for recovery and CO_2 emissions are reduced. The percentage of capital and operating costs of VAPEX versus SAGD are 75% and 50%, respectively. Within the THAI system, air injected through a vertical shaft at the "toe" forces bitumen which has been combusted underground to flow as oil to a recovery well at the "heel", as depicted in FIG. 7. A drawback of THAI is that it produces more CO_2 (McKenzie-Brown, 2009).

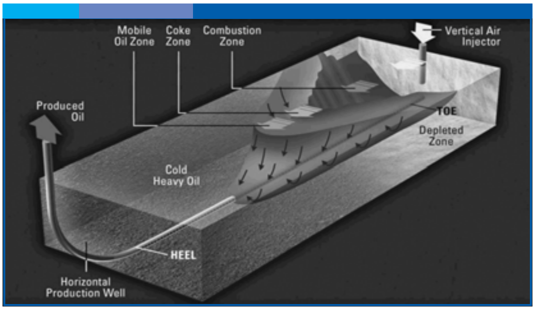

FIG. 7. THAI Process (Petroleum World, 2004)

Bitumen can be upgraded employing two main procedures: coking to remove carbon and hydro-cracking to add hydrogen to produce a variety of different oil-based products. Currently, about 60% of the bitumen produced in Alberta is upgraded in the province while 10% is delivered to other provinces in Canada and 30% to the United States for further processing (Prebble et al., 2009; ERCB, 2009; Edmonton Journal, 2008).

Unfortunately, the amount of raw bitumen exported outside of Canada may increase to 50% by 2019 (Hipel and Bowman, 2011). Hence, Alberta, in particular, and Canada, overall, have an opportunity to substantially increase the "value-added" to the oil sands industry by doing all of the refining in Canada and thereby creating more highly skilled jobs, enhancing profits, reducing the need to build more pipelines to ship raw bitumen to the US, keeping oil sands environmental problems more concentrated so that associated cleanup and recycling can be done more effectively, and expanding refining technologies. In a recent report, the Government of Alberta (2009) recognized the importance of some of the foregoing issues. Since, as explained below, the oil sands industry uses substantial amounts of water and produces a range of environmental impacts like large-scale holding ponds containing toxic wastes, it makes sense that Canada should reap the full value-added benefits of its oil sands industry. In turn, this would meaningfully contribute towards Prime Minister Harper's (2008) stated vision of Canada becoming an energy superpower, and the Canadian Academy of Engineering's goal (Bowman and Griesbach, 2009; Bowman et al., 2009) of Canada taking systematic steps to be a "sustainable" energy superpower.

In 2008, Canada exported about 1.9 million barrels of oil to the US, which constitute 19% of the American oil imports, making Canada the largest supplier of oil to the US and the US, in turn, Canada's largest oil customer. Of this volume, 1.7 million barrels per day were provided from Western Canada (CAPP, 2009).

In fact, according to the National Energy Board (NEB, 2004), 75% of Canada's nonconvention al oil exported to the United States is transported to the Petroleum Administration for Defense District II (PADD, built during World War II to organize and distribute oil to five districts in the US) located in the Midwest where there is substantial refining capacity. If Canada's oil sands production level of 5 million barrels per day in 2030 is achieved and export levels are maintained, the US will import about 4.5 million barrels per day from Canada or approximately 30% of all US crude oil imports. No doubt, emerging industrialized countries like China and India, will also want to buy Canadian oil. Therefore, it is essential that Canada gain full control of value-added to not only oil, but also to its other natural resources, including water.

This advice is put forward as a recommendation in Section 6.3.1. Bitumen from Alberta is now being refined into value-added fuel in the US and sold back to Canadians at a premium (Marsden, 2008, p. 57). A further complication to the export of oil and other resources to the USA is Article 605, the proportionality clause of the North American Free Trade Agreement (NAFTA) (Section 3.5), which compels Canada to sell to the USA the exact percentage of oil exports that prevailed over the previous three years, even if Canada urgently needs the oil for its own purposes. Over the years, oil sands activities have contributed considerably to Canada's economy. For example, the oil sands industry expects the annual capital expenditures to be generated in the range of about $8 billion to $12 billion (Richardson, 2007). Between 2000 and 2020, the Canadian Energy Research Institute (CERI) has estimated that the total economic impact of oil sands activities will create a GDP benefit of $885 billion. In Alberta, oil sands activities as a percentage of Gross Domestic Product will increase from 15% of GDP in 2006 to 20% in 2011 (Mourougane, 2008). In fact, because the royalty and tax charges from the oil sands project are extremely low, the total cost per barrel of oil from the oil sands project is less than the total cost per barrel of conventional oil (Humphries, 2008).

Although this policy may stimulate growth, authors, such as Marsden (2008) and Nikiforuk (2008) point out that jurisdictions such as Norway and Alaska are benefiting financially much better than Alberta, because their revenue policies mandate that significantly larger amounts of their non-renewable resource money directly benefits their citizens. Hence, for instance, the Alberta Heritage Fund, Alaska Permanent Fund and Norway's fund for their citizens contained about 15.4, 37 and 306 billion dollars, respectively, in 2006. One loophole in the Alberta policy is that oil sands companies only pay 1% of their revenues as royalties and this does not increase to 25% until it has paid off its entire capital cost. Accordingly, oil sands extraction companies are being encouraged to expand, and requested permits for expansion by existing and new companies are never refused. Former Alberta Premier Lougheed believes that the expansion is taking place far too quickly without due regard to the environment and societal issues. Furthermore, Hipel and Bowman (2011) point out that Alberta and Canada are losing economic, employment and technological benefits by allowing large quantities of unprocessed bitumen to be exported. Currently, about 30% of unprocessed bitumen is being shipped outside of Canada and this could increase to 50% by 2019. Canada clearly requires a policy in which all of its natural resources, including oil, must have strong "value-added" components.

By emitting 2% of the world's total global greenhouse gas (GHG) emissions, Canada ranked ninth in the world in 2005. Within Canada, oil sands GHG emissions account for 5% of the nation's total emissions (CAPP, 2008a). However, per capita, Canada is the second largest GHG emitter next to the USA (Mourougane, 2008). Within Alberta, the oil sands industries account for 23.3% of GHG emissions which is second to the utilities sector at 43.6% (Alberta Environment, 2008). Even though GHG emissions per barrel from oil sands are decreasing steadily due to improved technologies and procedures, the GHG emissions from oil sands are expected to increase nearly three times by 2010 when compared to 2006 because of greatly expanded extraction of bitumen (Grant et. al., 2009).

Oil sands operations require two to six barrels of water for every barrel of oil produced (PTAC, 2007; Eyles and Miall, 2007). These operations are consuming nearly 1% of the Athabasca River's average flow (Hrudey et al., 2010), which is enough water to sustain a city of two million people per year (Woynillowicz and Severson-Baker, 2006), and its consumption from the river is forecasted to double in the future. Moreover, two thirds of all water consumption from the Athabasca River is consumed by the oil sands industry (CAPP, 2008b). Because the production from oil sands is predicted to increase rapidly, water consumption is also expected to grow. Therefore, reducing the water consumption and increasing the water return volume are major challenges that must be overcome.

Besides water quantity, water quality is a major issue in the oil sands. After bitumen is extracted from oil sands, the remaining materials, consisting of residual sands and polluted water, are sent to settling ponds, referred to as tailings ponds. Each day, about 1.8 million m^3 of toxic tailings waste is produced. These tailings ponds cover around 130 km^2 and, taking into account both approved and planned projects, the total size of tailings ponds will reach 220 km2 having a volume of 11,648 million m^3 (Grant et al., 2008). Although the risk may be low, the human-made dykes containing tailings ponds could fail and thereby release massive quantities of pollutants into receiving bodies of water, such as the Athabasca River. Wastewater could also leak from tailings ponds into the ground and surface water. However, movement of surface water into the groundwater through the clay bottom material of the wastewater storage ponds is extremely slow with percolation rates of about 10-9 m/s. Low permeability clay is continuously being added at the base, meaning much more than several meters of clay forms the barrier. As a result, companies claim that the Athabasca River is not being contaminated by their tailings ponds and less oily material may be entering the Athabasca River now than before the development due to the blockage of naturally oily leaching materials. However, an estimate by Environmental Defence (cited by Hrudey et al., 2010, p. 111) suggests that seepage of polluted water from all tailings ponds is currently at a rate of some 11,000 m^3/day. Evaporation and reuse of treated tailings pond water are ways for reducing the size of the tailings ponds, in addition to approaches for decreasing overall water demand by the oil sands industry. No tailings ponds have as of yet been fully reclaimed (Hrudey et al., 2010).

Contrary to the findings of the industry-funded Regional Aquatic Monitoring Program that there is no evidence of oil sands developments having a detrimental impact on the Athabasca River, recent independent studies have shown that there is a significant level of dissolved polycyclic aromatic compounds (PACs), a pollutant that is detrimental to human and aquatic life, in the vicinity and downstream of oil sands developments (Kelly et al., 2009), and that the 13 elements considered priority pollutants under the US Environmental Protection Agency's Clean Water Act are being released to the Athabasca River and its watershed by the oil sands industry (Kelly et al., 2010). The oil sands are extensively exposed along the banks of the Athabasca River and its tributaries, and some, at least, of the pollution may be attributable to natural seepage of the bitumen into the groundwater and surface waters. Further studies need to be undertaken to attain a fuller understanding of the impacts and origin of pollutants in the oil sands region. Currently, no research programs are in place to investigate the issue of groundwater pollution. Kim et al. (2011) employed systems methodologies to investigate water quantity and quality problems in Canada´s oil sands from a multiple objective decision making viewpoint.

The area of land disrupted by surface mining is about 3,500 km^2, of which only 0.2% of the land has been reclaimed (Grant et al., 2008) as the mining operations in these areas are not yet complete. Such a massive change of landscape can be highly destructive to ecosystems. By 2008, surface mining had destroyed 530 km^2 of Canada's Boreal Forest (Kelly et al., 2010), an enormous region stretching east to west across Canada's mid-section (FIG. 8). It is in fact "one of the largest intact forest and wetland ecosystems remaining on Earth" (Environment News Service, 2007). On December 14, 2009, a group of prominent international scientists sent an open letter to the government of Canada, as well as to the seven other boreal forest nations, underscoring the importance of boreal forests as a carbon depository and urging the government to take decisive actions to safeguard this crucial ecosystem.

A statement from the group accompanying the release of the report asserted that boreal forests are "not only the cornerstone habitat for key mammal species, but one of the most significant carbon stores in the world, the equivalent of 26 years of global emissions from burning fossil fuels, based on 2006 emissions levels. Globally, these forests store 22% of all carbon on the earth's land surface" (Braun, 2009). The report explains that carbon is stored not only in the forest vegetation, but, more importantly, in "the associated soils, permafrost deposits, wetlands and peatlands" (Carlson et al., 2009). When the forest vegetation or soils are disturbed by climate change or direct human intrusion, the stored carbon is released and the carbon sequestration capability of the forest is diminished (Carlson et al., 2009).

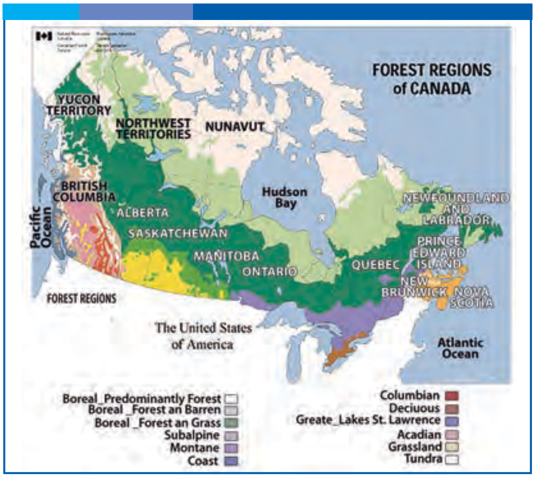

FIG. 8. Canada's Boreal Forest (NRCan, 2007)

In the view of David Schindler, Killam Memorial Professor of Ecology at the University of Alberta, this process will accelerate climate change to an extent that will dwarf the most recent estimates from the Intergovernmental Panel on Climate Change (Schwartz, 2010). Moreover, the boreal forests of the Mackenzie River Basin, where the oil sands are being developed, are important for providing rain to Manitoba, Ontario and Quebec via transpiration (Wood, 2010). A further effect of surface mining is that it alters the flows of both ground and surface waters and possibly changes their quality. This consequence will have further impacts on boreal forest, as the Mackenzie River is crucial for maintaining the boreal forest that follows it north as far as the Arctic Ocean (Wood, 2010). The health of the Mackenzie River is especially critical to the northern Aboriginal communities living alongside it, who rely on it to maintain their traditional way of life and have a constitutional guarantee to this right (Miltenberger, 2010).

Henry Vaux Jr., Professor of Resource Economics at the University of California and Emeritus Chair of the Rosenberg International Forum on Water Policy, contends that the monetary value of the ecological services provided by the Mackenzie ecosystem, including carbon credits, vastly outweighs the profits from oil sands developments (Wood, 2010). In light of the importance of the Mackenzie River Basin and the serious threats it is facing, Rob de Loë, Professor and University Research Chair in Water Policy and Governance at the University of Waterloo, recommends that Alberta and the four other provinces and territories that share the basin, as well as the Aboriginal groups in the region, adopt a collaborative approach to managing the Mackenzie Basin, incorporating "accepted international norms and best practices" (de Loë, 2010). The in-situ method of extraction might make the degradation of the landscape to appear to be less serious. Nonetheless, in-situ operations require infrastructure such as roads, transmission lines, and pipelines, and therefore can also affect both flora and fauna negatively over the long term (Richardson, 2007). By the way in which in-situ mining is executed, it can have negative effects upon groundwater resources, although it should be noted that the groundwater is already naturally contaminated.

Greatly increased demand for water by the oil sands industry coupled with drier periods brought about by climate change means that water resources will be further stressed in terms of decreased availability and deteriorating quality. Mannix et al. (2010) emphasize that a long-term, cost-effective strategy is needed to properly manage the implementation of water restrictions in the oil sands. Bruce (2006) points out that although winter low flows in the Athabasca River have declined dramatically in recent years, water has been allocated for future projects based on the much higher long-term average winter flows. Water should, of course, be allocated fairly in a sustainable fashion among competing users, including the environment, perhaps following the fairness allocation approach designed by Wang et al. (2008). Fairness can be encoded into governance procedures in which independent regulators and inspectors ensure compliance to the associated water quantity and quality laws and regulations. Overall fairness also entails making sure that revenues from the oil sands are equitably shared among stakeholders and that all “value-added” activities connected to the oil sands are carried out in Canada.

New extraction projects in the oil sands are making use of deep saline groundwater, instead of fresh surface waters, and companies are also improving their ability to recycle the water multiple times, which is significantly reducing demand for the fresh waters of the Athabasca system. Another “game changer” in the oil sands is the development of a new technique to speed up the sedimentation of the clay in the tailings pond, and thereby reduce the time required for their reclamation. Polyacrylamide is a substance used in municipal and industrial wastewater treatment plants to flocculate solids. Suncor is developing a method for the application of this substance to the tailings ponds, and projects that it will permit the ponds to be sedimented, dried out and undergo reclamation in ten years, instead of the 40 years under the present reclamation methods.

Two important independent studies of the oil sands were released in December 2010. The Royal Society of Canada commissioned an expert panel report on the health and environmental impacts of Canada´s oil sands industry. The report concludes that, although the environmental and health effects of the oil sands have thus far not been as drastic as some have alleged, both the Alberta and federal governments are failing to implement monitoring, assessment and regulation of the oil sands to an extent that is keeping pace with the rapid expansion of oil sands development (Hrudey et al., 2010). Moreover, an Advisory Panel to the Federal Minister of the Environment consisting of five leading environmental scientists, including co-author of this paper Dr. Andrew D. Miall, conducted a review of the current state of environmental research and monitoring in the region surrounding oil sands developments, and made recommendations regarding monitoring and best practices to ensure that the oil sands are developed in an environmentally sustainable manner.

Assessing the existing approaches to monitoring the oil sands to be inadequate and lacking in coordination, the Panel recommends "that a shared national vision and management framework of aligned priorities, policies and programs be developed collaboratively by relevant jurisdictions and stakeholders" in order to establish a monitoring and reporting system for the oil sands that is holistic and integrated, adaptive, scientifically credible, and transparent and accessible (Dowdeswell et al., 2010).

4.4 Red River Basin: Ecosystem Security and Flooding

As shown in FIG. 9, the Red River Basin overlaps with the American states of North Dakota and Minnesota, as well as the southern part of the Canadian province of Manitoba in the center of North America. The Red River flows for over 800 km from south to north where it empties into Lake Winnipeg north of the City of Winnipeg. Although the Red River region is best known for extensive flooding, it also has the potential for serious water quality problems.

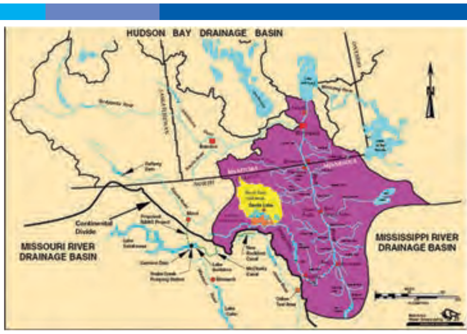

FIG. 9. Red River Drainage Basin (Manitoba Water Stewardship, 2010)

One environmental dispute arising between the United States and Canada, which was amicably resolved by a ruling of the International Joint Commission (IJC) (Section 3.2), is the conflict arising over the proposed construction of a large irrigation project called the Garrison Diversion Unit (GDU). Under the GDU plan of 1965, the Americans would transfer water from Lake Sakakawea in the Missouri River Basin, formed by the completion of the Garrison Dam on the Missouri River in 1955, via the proposed McClusky Canal over the great divide to the Hudson Bay Drainage Basin where the water would be used to irrigate crops in the northeastern part of North Dakota. The polluted runoff from the irrigated fields would flow via the Souris and Red Rivers into Canada from where it would eventually enter Hudson Bay. In addition to increased flows, pollution from fertilizers and pesticides, and draining of wetlands, the major concern was the possible introduction of foreign biota from the Missouri River Basin into the Hudson Bay Drainage Basin, which could, for example, destroy the fishing industry in Lake Winnipeg in Manitoba. Accordingly, the US and Canadian governments called upon the IJC to make a recommendation. In its report of 1977, the IJC ruled that all portions of the project except the Lonetree Reservoir should be discontinued. The Garrison Diversion Unit Commission, created by the US Secretary of the Interior on August 11, 1984, essentially recommended in its report of December 20, 1984, that the GDU project not continue. Strategic analyses of the GDU controversy are provided by Hipel and Fraser (1984) and Fang et al. (1993, Ch. 6).

An ongoing environmental conflict between the US and Canada which has not yet been satisfactorily resolved is the Devils Lake Outlet Diversion conflict which has been formally studied strategically by Ma et al. (2011) and described in many newspaper articles and reports (Noone, 2004, 2005; US Army Corps of Engineers, 2005; North Dakota State Government, 2001; North Dakota State Water Commission, 2010). Because Devils Lake, located in North Dakota, is land-locked and water drains towards it (FIG. 9), evaporation and runoff from farm land has caused the lake to be severely polluted. Since the last ice age, Devils Lake has fluctuated between being dry and having a high water level, as it does now.

The current elevated level of Devils Lake, as well as increased Red River flooding, could be due to augmented flows of moisture-laden warm air from the Gulf of Mexico to the Great Plains in combination with climate change. In order to alleviate the high water levels and associated flooding, the state of North Dakota decided to construct independently a temporary emergency outlet called the Peterson Coulee Outlet, rather than wait for the US Army Corps of Engineers to build an outlet which was delayed as a result of environmental concerns. Because the outlet empties into the Sheyenne River, a tributary of the Red River which flows northward into Canada, the outlet poses potential risks in transferring invasive species and degrading water quality in Manitoba, which can negatively affect people's health, fisheries and the tourist industry (Byers, 2005).

Therefore, in April 2004, the Canadian Government formally requested that the Devils Lake outlet proposal be referred to the IJC to conduct an independent, impartial review of the risks. Because no response from the US Government was forthcoming, the Canadian Government continued to press the US Government to agree to an IJC reference, while North Dakota kept constructing its own project. On August 5, 2005, Frank McKenna, Canada's ambassador to the United States, suddenly announced a negotiated deal with North Dakota had been reached in which the state would add a temporary gravel barrier as the filter to the project before it begins operating (CBC News, 2005). The emergency outlet diversion has been completed and since August 15, 2005, water from Devils Lake has been draining into the Sheyenne River (Lambert, 2005). However, since an advanced permanent filter still has not been installed the conflict is ongoing (Owen and Rabson, 2010).

When North Americans think of the Red River, they usually envision massive widespread flooding. In fact, the Red River system is prone to serious flooding and in recent years major floods occurred in 1997, 2009, and 2011 (CBC Manitoba, 2011). In part, the flood danger results from the fact that over much of its length the river lies within a flat floodplain, in contrast to the incised nature of many other western rivers such as the Bow and Saskatchewan Rivers. In addition, the substrate beneath the river over much of its course consists of a thick, impermeable clay, which allows very little of the spring runoff to percolate into the ground.

A further complication is that ice jams can occur in the Red River in the spring since the river flows from the south to north where thaws take place later. FIG. 10 displays the flooding which occurred in April and May of 1997 for which the resulting lake was up to 40 km wide. At its peak on May 4, 1997, more than 2,560 km^2

of land was inundated in Manitoba to form Canada's "Red Sea". The total damages incurred in the US and Manitoba was $3.5 billion and $500 million, respectively. The American Cities of Grand Forks and East Grand Forks received extensive damage from the flooding. Fortunately, the City of Winnipeg was protected by a floodway built between 1962 and 1968 as a joint federal/provincial/municipal project, following severe inundation of the city in 1950, which displaced some 100,000 residents.

This channel has proved its worth several times, especially during the 1997 flood as depicted in FIG. 10. Clearly, Canada has done an outstanding job in flood plain management within the Red River Basin – this knowledge, technology and expertise could be utilized elsewhere in Canada and the Americas. Nonetheless, Canada still has much to learn about being proactive and adaptive in flood protection and evacuation as evidenced by the flooding of the Saguenay-Lac-Saint-Jean region which occurred in Quebec after two days of torrential rainfall in July, 1996.

This worst flood in Canadian history, which was only supposed to happen once in 10,000 years, resulted in 10 deaths, $800 million in damages, and the destruction of 1,718 houses and 900 cottages (Grescoe, 1997). In this and similar areas, flood control structures are required due to the geography of the region. Flood plain management through zoning and restriction of construction in the flood plain is not as widely practiced as required to reduce the cost of flood damage.

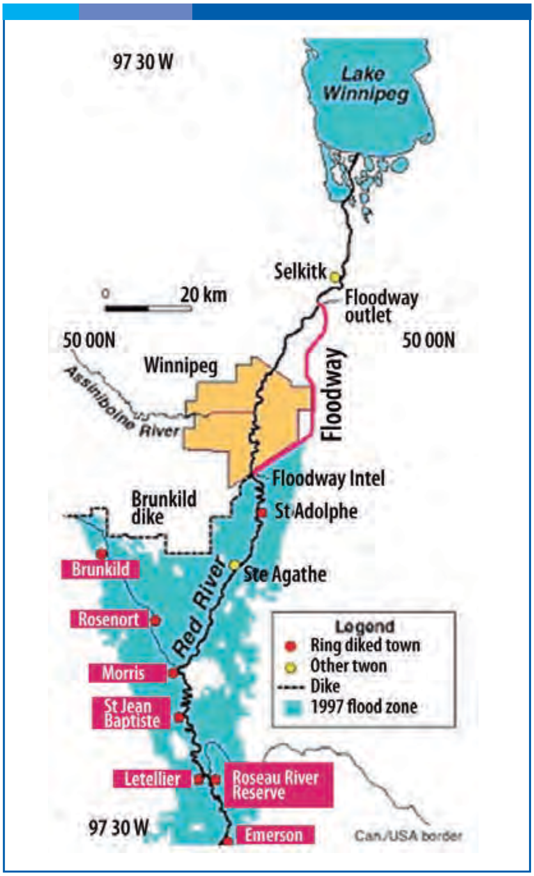

FIG. 10. Red River 1997 Flood Zone (NRCan, 2008)

4.5 The Great Lakes: Pollution, Diversions and Fluctuating Water Levels

The Great Lakes Basin is located in the heartland of North America and is shared by Canada and the USA. FIG. 11 portrays a map of this unique and prosperous basin which contains the largest supply of fresh surface water in the world. All five of the Great Lakes eventually flow into the St. Lawrence River which empties into the Atlantic Ocean. Because less than 1% of the water in the Great Lakes is renewed annually, the waters of the Great Lakes are essentially a non-renewable resource (i.e., the retention time is greater than 100 years). As can be seen in

FIG. 11, the eastern section of this map also includes river basins that drain directly into the St. Lawrence River. From east to west, the Great Lakes Basin spans more than 1,200 km and encompasses an area of more than one million km^2 which is the home for about 40 million Canadians and Americans.

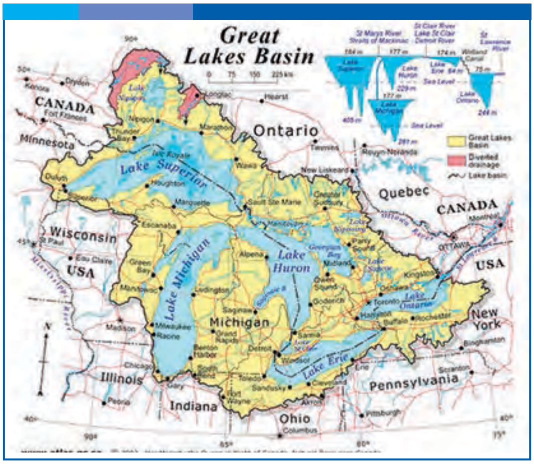

FIG. 11. Great Lakes – St. Lawrence River Basin (NRCan, 2003)

Fertile agricultural land exists in many regions in the basin, such as in the southern part of Ontario. Sufficient precipitation is available throughout the growing season to support forest cover and agricultural activities, while during the winter season, snow blankets the ground for quite a few months with very cold weather conditions in the northern regions of the basin. Groundwater contributes significantly to the overall water supply in the Great Lakes Basin and, for example, accounts for about 42 percent of the yearly supply to Lakes Huron and Ontario (directly, as well as indirectly by contributing to river inflows). The hydraulic characteristics of the Great Lakes system such as water levels are mainly the result of natural fluctuations rather than human intervention. Control works, operated under the authority of the IJC (Section 3.2), are in place in the St. Mary's River at the outlet of Lake Superior and in the St. Lawrence River below the outflow from Lake Ontario. Ocean-going ships can travel from the far western end of Lake Superior through the Great Lakes and eastwards along the St. Lawrence River for a distance of more than 2000 km via a navigation system referred to as the St. Lawrence Seaway. As part of this system, the Welland Canal joining Lake Erie to Lake Ontario permits ships to circumvent the Niagara Falls. Water is diverted around Niagara Falls to allow hydroelectric energy to be generated on both sides of the Canada/US border due to a hydraulic head afforded by the Niagara Escarpment.

Besides agriculture and mining activities, the basin also contains many prosperous industrial centers. The City of Toronto, for instance, is Canada's largest city and possesses a rich diversity of industrial enterprises. The City of Detroit, located in Michigan where the Detroit River drains Lake Superior into Lake Erie, is the most important center for automobile production in the USA. Moreover, much of the historical, cultural, economic and political development of Canada and the USA has occurred in the Great Lakes Basin. As shown in FIG. 1 and 11, two Canadian provinces and eight American states control land that is part of the basin. Therefore, a total of twelve governments, two federal plus ten state or provincial governments, share jurisdiction over the Great Lakes Basin and effective management can only be accomplished on the basis of cooperative arrangements. As a direct result of the two nations' determination to be friendly neighbours and trading partners, there have been no wars between

Canada and the USA since the War of 1812-14 when invading American forces attacking at many points in the Great Lakes region shown in FIG. 11 failed to wrest control of Upper Canada (now Ontario) and Lower Canada (Quebec) from Great Britain.

The fundamental international legal document governing the use of the waters of the Great Lakes Basin is the Boundary Waters Treaty of 1909 described in Section 3.2. Almost all of the international agreements regarding water quantity and quality problems in the Great Lakes Basin that have been jointly created and signed over the years are founded upon the powers and "spirit of cooperation" enshrined in this well-crafted 1909 treaty. Accordingly, even though improvements could be made, the Great Lakes system has been remarkably well managed and thereby constitutes a model for other nations to consider following as they develop their own bilateral and multilateral agreements over water.

Consider what has happened with respect to water quality in the Great Lakes. Earlier reference studies executed by the IJC led directly to the Great Lakes Water Quality Agreement of 1972, which was primarily concerned with reducing phosphorus levels in Lakes Ontario and Erie shown in Figure FIG. 11. This 1972 agreement was superseded by the Great Lakes Water Quality Agreement of 1978, which put forth an ecosystem approach to water quality management to restore and maintain the chemical, physical and biological integrity of the Great Lakes Basin Ecosystem. Both the 1972 and 1978 agreements contained phosphorous loading and toxic chemical limits. A Protocol signed in 1987 amended the 1978 Agreement with the goals of strengthening the programs, practices and technologies contained in the earlier agreement. However, the Protocol gave the IJC a less central role, thereby reducing government accountability.

Because the Great Lakes Basin falls within the territories of eight states and two provinces, it is not surprising that these political entities have cooperated with one another over the years in the management of the Great Lakes Basin. Specifically, on February 11, 1985, the Great Lakes Charter was launched as a means for the Great Lakes states and the provinces of Ontario and Quebec to manage the water resources of the Great Lakes in a cooperative fashion. A key principle of the Charter is that the planning and management of the water resources of the Great Lakes Basin should be based upon the integrity of the natural resources and ecosystem of the basin. Additionally, the Basin should be treated as a single hydrological system that transcends political jurisdictions. A key clause is that "diversions of Basin water resources will not be allowed if individually or cumulatively they would have any significant adverse impacts on lake levels, in-basin uses, and the Great Lakes Ecosystem".

In the spring of 1998, the Ontario government approved a permit for Nova Group of Sault Saint Marie in Ontario to remove 160 million gallons of water per year from Lake Superior for exporting to Asia (Section 4.7). Even though the Ontario Government later rescinded the license, the public backlash in Ontario and the United States led to a review of bulk water removals by the IJC. This also prompted the Great Lakes Governors to form a Working Group to study this issue in 1999, which Ontario and Quebec joined later in the year. Subsequently, the Great Lakes Governors and two Premiers signed the Great Lakes Charter Annex 2001 on June 18, 2001 in Niagara Falls, New York, as an amendment to the Great Lakes Charter of 1985. Within Annex 2001, parties agreed to prepare basin-wide binding agreements in contrast to the voluntary obligations of the original 1985 Charter. On December 13, 2005, the eight Governors and two Premiers signed the Great Lakes-St. Lawrence River Basin Sustainable Water Resources Agreement and endorsed the Great Lakes-St. Lawrence River Water Resources Compact, which became law on December 8, 2008. Key components of the agreements are the ban of new diversions of water from the Basin except for some special cases, and economic development must be executed via the sustainable use of water.

The substantial monthly and yearly fluctuations in water levels present significant problems with respect to shoreline flooding and erosion, hydroelectric power generation, navigation, docking, and the loading and unloading of transported materials (Environment Canada, 2009; Section 5.5). In fact, in 1985 and 1986, following almost 20 years of above-average precipitation and below-average evaporation, all lakes except Lake Ontario reached their highest levels in the 20th century. In combination with high water levels, storm activity caused severe flooding, erosion of shorelines, and extensive damage to lakeshore properties. In response to the issue of fluctuating water levels in the Great Lakes-St. Lawrence system and the widespread public concern over the risk of costly damage, the Canadian and US governments requested the IJC to carry out an investigation and make appropriate recommendations. The IJC created the Levels Reference Study Board which eventually released its final report on March 31, 1993. To alleviate the adverse consequences of fluctuating water levels, the Board recommended a combination of actions related to land-use regulatory practices and that no further consideration be given to the regulation of water levels via hydraulic structures (Levels Reference Study Board, 1993; Rajabi et al., 2001; Yin et al., 1999).

4.6 Hydroelectricity in Quebec: the James Bay Project and Churchill Falls

Canada is the second-largest producer of hydroelectricity in the world (behind China), producing 13% of global hydroelectricity (International Energy Agency, 2008).

Hydroelectricity accounts for about 60% of Canada's overall electricity production and 97% of its renewable energy generation (Government of Canada, 2009). In Quebec, over 95% of the electricity distributed by Hydro-Québec, the province's leading electricity provider, is hydroelectric (Hydro-Québec, 2009). Canada is currently "a world leader in hydropower production, with an installed capacity of over 70,858 megawatts (MW), and an annual average production of 350 terawatt-hour (TWh)" (Government of Canada, 2009). Canada has the greatest hydroelectric capacity in the world (Canadian Geographic, 2010b). Its current hydroelectric production has the potential of being more than doubled (Government of Canada, 2009). Canada is the largest supplier of electricity to the US, primarily in the form of hydroelectricity (Burney, 2009), exporting 6 to 10% of its electrical generation to the US (Centre for Energy, 2010). Most provinces have an electrical connection with adjacent US states and all of the provinces are interconnected with neighbouring provinces, allowing exchanges of electrical power. Canadian utilities and governments are currently striving to augment east-west electricity flow amongst provinces (Centre for Energy, 2010).

Canada's largest hydroelectric-power development is the James Bay Project, shown in FIG. 12, which is located on the east coast of James Bay in the province of Quebec and supplies over half of Quebec's hydroelectric power. The project was initiated in 1971 by Hydro-Québec and the Quebec government. A total of nine generating stations have been constructed and two more stations are currently under construction. The project currently has a generating capacity of 16,000 MW, which is three times that of the Niagara Falls stations and eight times that of Hoover Dam. If the project were expanded to incorporate all of the other planned dams and projects, it would generate 27,000 MW, becoming the world's largest hydroelectric system (Academic dictionaries and encyclopedias). Although hydro-electric power has several advantages over other energy sources, such as not producing greenhouse gases during electricity generation and having an extremely efficient conversion rate of water flow to electricity production (Armin, 2010), the James Bay Project has generated considerable controversy on account of its negative environmental and societal impacts. Nine free-flowing rivers were diverted and dammed by the project, flooding 11,500 km^2 of boreal forest. The project also caused the release of mercury into the water system, contaminating fish and contributing to the death of 10,000 caribou. Moreover, the project devastated the livelihood and way of life of indigenous people living in the affected area (Canadian Encyclopedia, 2010).

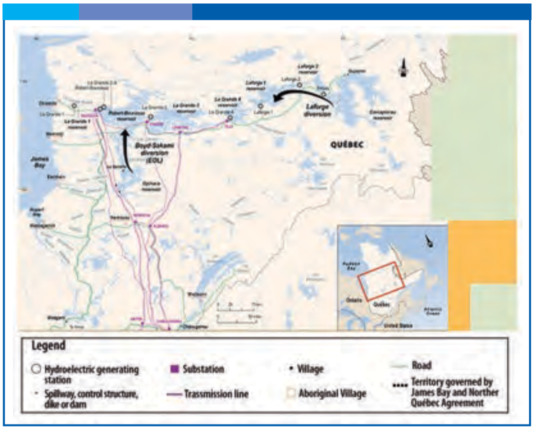

FIG. 12. James Bay Project (Hydro-Québec, 2010)

The Churchill Falls Generating Station is another major source of hydroelectric power exported to Quebec that has stirred controversy, but primarily for political reasons. The Churchill Falls Station is one of the largest underground power stations in the world, having a rated capacity of 5,428 MW (Nalcor Energy, 2010a). Churchill Falls is located in Newfoundland and Labrador (NL), which borders the north-east corner of Quebec. Since NL does not share a border with any other province or American state and Quebec does not allow it to transfer power across its borders, it is compelled to sell its electricity solely to Quebec. Shortly before the signing of the deal between the Churchill Falls Labrador Company (CFLCo) and Hydro-Québec in 1968, Hydro-Québec acquired insider information that CFLCo was on the verge of bankruptcy. Hydro-Québec exploited this knowledge by changing the terms of the deal such that it would purchase power from CFLCo at an extremely low cost and the expiry of the contract was extended from 2016 to 2040. Quebec has subsequently made windfall profits from selling this power to the US, while NL has accrued comparatively meagre profits. The contract has been challenged in court twice by the NL government, but the courts have upheld it each time (Montreal Gazette, 2005). The creation of a new station, the Lower Churchill Falls Project, has been planned and proposals for its construction are currently being reviewed (Nalcor Energy, 2010b).

4.7 Threat of Water Exports

Canada has often failed to take full advantage of its natural resources from economic, environmental and societal perspectives. For example, much of Canada's forestry resources are shipped to other countries as unprocessed logs or raw lumber and significant amounts of the oil recovered from the oil sands (Section 4.3) are not being refined in Alberta or elsewhere in Canada. There are thus very limited value-added components to these resources, resulting in massive losses in jobs and profits. Furthermore, Canada is particularly vulnerable to losing control of its valuable fresh water resources and potentially suffering extensive ecological damage. As noted in Section 3.5, contrary to the claims of the former Progressive Conservative government which negotiated the North America Free Trade Agreement (NAFTA), Canadian freshwater is not protected under NAFTA (Nikiforuk, 2007).

Private companies, both within and outside of Canada, would like to export Canadian water in bulk quantities in order to make large profits for themselves. In 1998, the province of Ontario issued a permit to Nova Group Ltd. of Sault St. Marie for the export by tanker from Lake Superior of 4 to 6 million m^3 of water per year.

The federal government announced its opposition to the permit and under public pressure the Ontario Ministry of the Environment cancelled Nova's permit. In February 1999, the federal government launched a strategy consisting of three components to prohibit the bulk removal of water from Canadian watersheds. The first is the establishment of a Canada-wide accord with all of the provinces banning bulk water removal in which each province creates legislation to meet this goal. Within the second component, Canada put forward a joint reference with the United States to the International Joint Commission (IJC) to investigate the effects of water consumption, diversion and removal, including for export from boundary waters. Subsequently, in February 2000, the IJC submitted its final report entitled "Protection of the Waters of the Great Lakes", in which it recommended a precautionary approach (SEHN, 1998) whereby water removal not be authorized unless it can be shown that such removals will not adversely affect the integrity of the Great Lakes ecosystem.

Finally, in the third component of its strategy, the federal government amended the 1909 International Boundary Water Treaty Act by provisions that give the Minister of Foreign

Affairs the authority to prohibit bulk water removals from boundary waters. To further strengthen the protection of Canada's waters, the Canadian Water Issues Council (2008) has formulated a model federal statute that would prevent the bulk removal of freshwater from Canada´s natural basins. By not allowing water to be exported out of its natural basins, ecological integrity is preserved.

On December 13, 2005, the Governors of eight American states bordering the Great Lakes and the Premiers of Ontario and Quebec signed agreements to provide unprecedented protection for the Great Lakes. Under the Great Lakes – St. Lawrence River Sustainable Water Resources Agreement, long-range diversions out of the Great Lakes basin are prevented, although, as critics, point out, diversions within the basin are not. An attractive feature of the Great Lakes – St. Lawrence River Basin Water Resources Compact is that it promotes the principle of adaptive management (Section 6.2) approach to water governance.

As an illustration of how NAFTA can exacerbate conflict over water exports, in spite of existing laws to maintain the integrity of ecosystems, consider the Sun Belt dispute which was systematically studied by Obeidi and Hipel (2005) and Hipel et al. (2008a), who provide detailed background information and references. Briefly, in the late 1980s the government of British Columbia (BC) granted licenses to investors, including Sun Belt Corporation Inc. of California and a Canadian partner called Snowcap Water Ltd., to withdraw fresh water in bulk quantities because the BC government thought that the province had abundant water supplies. However, as a result of stiff opposition from environmental groups and concerned citizens, the BC government imposed a temporary moratorium on March 18, 1991, which was made permanent in June 1995 by the provincial Water Protection Act. Because Sun Belt failed to reach a settlement with respect to its lawsuit against the BC government for damage claims, ultimately Sun Belt decided to take advantage of provisions under NAFTA (Section 3.5) to sue for monetary compensation. Specifically, in early 2000, Sun Belt served the Federal Government of Canada with a "Notice of Intent to Submit a Claim to Arbitration" in which it invoked Articles 1102, 1005 and 1110 in Chapter 11 of NAFTA, as well as Articles 26 and 27 of the Vienna Convention on the Law of Treaties.

This ongoing conflict, for which Sun Belt is seeking billions of dollars in lost profits and legal expenses, has been analyzed at different periods of time using conflict resolution techniques (Hipel et al., 2008; Obeidi and Hipel, 2005). Clearly, this type of resources dispute will only increase in the future as a direct result of the flawed design of NAFTA in which all of the legal power is accorded to the large corporations and the dispute resolution mechanism pits corporations in negative combative situations against elected governments and their citizens, rather than encouraging positive win/win resolutions, as is done under the Boundary Waters Treaty of 1909 which is administered by the International Joint Commission (Section 3.2).

Because of the aforementioned Great Lakes agreements, some people argue that at least the water in these lakes is protected from exploitation by large corporations at the expense of individual American and Canadian citizens living in the Great Lakes – St. Lawrence basin, as well as the environment. However, this may not be the case. As explained in detail by Hipel et al. (2008) and references contained therein, although a private company, McCurdy Enterprises, eventually failed to obtain permission to export water in bulk quantities from Lake Gisborne in Newfoundland, they predict that if the price of water rises to a sufficiently high level, a future government of Newfoundland and Labrador may permit the exportation of freshwater in large quantities.

Because of NAFTA rules, if a commodity, such as water, is exported once, it can be exported in the future from anywhere in Canada, including the Great Lakes which are supposedly protected by other international agreements coupled with corresponding state and provincial laws.

Ironically, given the dispute about potential water exports from Lake Gisborne in Newfoundland, one of the authors observed bottled water from Lake Eugenia, north of Toronto, on sale in supermarkets in St John's in 2007. Bottled water has made for an enormously profitable industry, but makes no economic or scientific sense, especially given the fact that the per-litre retail cost of the water may be up to 3,000 times that of standard municipal tap water available from the faucets in the stores where the bottled water is sold. As is discussed further in Section 5.4, bottled water is a means by which water is already being exported out of Canada.

Virtual water represents another way in which vast quantities of water are currently being diverted out of Canada. Virtual water refers to the water required in the production of a good or service. For instance, the global average for the amount of water required to produce a cup of coffee is 140 L and the amount for 1 kg of beef is 16,000 L (Water Footprint Network, 2008). In fact, "seventy times more water is used in the production of the world's food supply than is directly consumed as 'water' by the world's householders" (Horbulyk, 2007). When products are exported from a country, all of the water that is "embedded" in those products is effectively exported out of the country. Canada is surpassed only by the US in the total amount of virtual water it exports (2003 International Year of Freshwater, 2003) through the export of such products as cereal crops, livestock and oil-bearing crops (Chapagain et al., 2005).

5. Water Problems Occurring in many Regions in Canada

A range of challenging water problems that are not mainly connected to one region but occur across Canada are put forward in this section. As explained in Section 5.1, groundwater resources are being utilized for drinking water, agricultural, industrial and commercial purposes in all of Canada's political jurisdictions. In many cases, groundwater tables are dropping where the underground water reserves are over-exploited and aquifers are being polluted as a result human-induced reasons such as brownfields, which are created by the pollution of land from industrial activities as discussed in Section 5.3. Both ground and surface water, as well as the atmosphere, are being contaminated by what are called Contaminants of Emerging Concern (CECs) in Section 5.2. Many people are concerned, for instance, over the health effects of the vast array of new chemicals being produced by industry, such as the pharmaceutical sector, that are entering the hydrological cycle portrayed in FIG. 3. Bottled water is produced in most regions of Canada with large-scale exports to other parts of the country and to other nations, as mentioned in Section 5.4. Moreover, in the form of virtual water, the total amount of water needed to grow a crop or make a product, water is being exported in other ways in large, but unseen, quantities. The ongoing dispute over threat of the direct exportation of water in bulk quantities is discussed in Section 4.7.

5.1 Groundwater over-Exploitation, Pollution and Restoration

The following is a summary of current and emerging groundwater issues in Canada, as highlighted by a report from the Council of Canadian Academies (CCA) (2009):

- Population growth and its increasing concentration in urban areas, with major implications for land-use planning and watershed protection.
- Intensification of agriculture, resulting in greater demands on groundwater and the ever-present risk of contamination by nitrates and other residues and pathogens (CCA has been asked by the Minister of Agriculture and by Agri-Food Canada to carry out a study to determine what additional science is required in order to manage the water demands of agriculture in a more sustainable manner).
- Increased exploitation of hydrocarbons and other mineral resources in response to global demand, creating new and growing pressures on the quantity and quality of adjacent water resources — both surface water and groundwater.
- The presence of contaminated sites (see Section 5.3 on brownfields) and the continuing need for remediation.
- The growing concern for groundwater source protection as a consequence of some or all of the foregoing.
- Threats to aquatic ecosystems and fish due to the low flow of streams that are fed by groundwater during dry periods.
- Transboundary water challenges and the ongoing need for cooperative management of water resources that straddle or cross the Canada-US border.
- The impact of climate change on the availability of our linked groundwater and surface-water resources, in addition to the increased demands placed on these resources (Section 5.5).

Estimates for 1995 show that groundwater accounted for only a little more than 4% of total fresh-water use in Canada, but this was roughly double the estimated amount of annual groundwater use between 1980 and 1990. The US uses vastly more groundwater than Canada, even on a population-adjusted basis (CCA, 2009).

"The primary use of groundwater in Canada varies regionally, from municipal purposes in Ontario, Prince Edward Island, New Brunswick and the Yukon, to livestock watering in Alberta, Saskatchewan and Manitoba, to largely industrial purposes in British Columbia, Québec and the Northwest Territories, and to domestic wells in Newfoundland and Nova

Scotia. Within each province there is variability in the spatial distribution of groundwater use, depending on local aquifer properties and surface-water availability. The dependence of provincial populations on groundwater for domestic needs ranges from 100 per cent in Prince Edward Island to about 23 per cent in Alberta. This wide variation illustrates the highly regional nature of dependence on groundwater." (CCA, 2009).

Although groundwater resources have been exploited for more than one hundred years, little systematic information is available regarding aquifer characteristics. The National Water Research Institute (NWRI) and the Geological Survey of Canada (GSC) are now collaborating on collecting this information, and applying modern geological methods to aquifer mapping and interpretation.

The Paskapoo aquifer of Alberta can serve as a typical example of an aquifer of considerable local and regional importance but which is only in the last few years receiving appropriate scientific attention. The Paskapoo is a sandstone formation that lies just below the surface cover of glacial sediments across much of Alberta. Some 65,000 wells have been completed in this unit, making it by far the most significant source of groundwater in the Prairies (information in this section from Grasby et al., 2008). The unit is under substantial pressure because of increasing population in both urban and rural parts of the province, and because surface water rights have now been virtually entirely allocated. The aquifer is of the "unconfined" type; that is, it is not covered by an impermeable layer, and therefore receives recharge over its entire area of occurrence. The average water level in Paskapoo wells has dropped by 3 m in the 47 years for which records are available, but it is unclear whether this reflects an actual drop (as a result of water use and drought) or because wells are now being drilled deeper into areas at which the water table is lower.

Currently, contaminant levels in the Paskapoo still appear to be low, with the exception of local anthropogenic chloride concentrations. Some 8% of private wells in Alberta exceed drinking-water guidelines for bacteria, and 92% exceed Canadian guidelines for one or more health and aesthetic parameters (i.e., qualities that affect taste or odour, stain clothes, or encrust or damage plumbing) (CCA, 2009). Grasby (2008) estimates that to accommodate projected future population growth across Alberta, a 50% reduction in per-capita water use will be required over the next 50 years. Limitations on both surface and subsurface water will be required.

The Township of Langley, near Vancouver, is cited as an example of a rapidly urbanizing agricultural community (its 2008 population of 100,000 is forecasted to reach 165,000 by 2023) that has experienced substantial groundwater declines and is taking steps to reverse them (CCA, 2009). Ongoing monitoring indicates declining water levels in the more intensively used aquifers, a trend that has been occurring for nearly 40 years. The declines are not due to changes in precipitation but are the result of groundwater overuse. Instituting water-demand management to conserve groundwater can result in significant savings. The Township estimates that meeting the goals of its proposed water management plans would result in a 30% reduction in overall water use with a savings of approximately $800,000 in 2007. It is far costlier to clean up agricultural and industrial contamination of groundwater than to undertake measures to prevent it (CCA, 2009). Some cases of groundwater contamination in Canada are well known. The Walkerton, Ontario, tragedy of May 2000 resulted in seven deaths and at least 2,300 individuals becoming seriously ill, as a result of a breakdown in the system of testing, chlorination and monitoring. It was ultimately determined that agricultural wastes were leaking into the town's water well, but routine test results were not performed properly and were, in any case, ignored at all levels of the municipal and provincial system that is supposed to be in place to prevent such occurrences (Hipel et al., 2003, for references and a risk assessment). The costs of investigating the problem were very high, as were the costs of putting a new system in place.

The cost of fixing Walkerton's water problem came to $64 million, the commission to investigate the event cost approximately $10 million, and over $65 million was paid in compensation to victims and their families (Wellington et al., 2007; The Canadian Press, 2008; Parsons, 2002).

Important changes to Ontario´s water laws came into effect as a result of the inquiry into the Walkerton incident. In his inquiry report, Justice O'Connor concluded that protecting water at its source is a key component of a comprehensive water management approach to guard against a similar occurrence, and made 22 recommendations regarding source protection. In order to implement these recommendations, the Ontario government instituted the Clean Water Act, requiring communities to develop and carry out a source protection plan for their municipal water supplies (Conservation Ontario, 2009).

An emerging issue concerning both surface waters and groundwaters has been created by new methods for the exploitation of shale gas. Widely dispersed natural methane gas can now be extracted from "tight" non-porous shales by the process of "fracking" — the use of large amounts of water, sand and chemicals injected into the subsurface under very high pressures (5,000-15,000 psi). The fracking process opens up incipient fractures and generates new ones in the shale, vastly increasing the surface area from which the gas may seep into the well bore. The development of this process, which requires the drilling of multiple horizontal wells, has changed the economics of natural gas completely, with this source now already providing 20% of all the gas produced in the United States (IHS, 2010).

Large reserves are predicted to be present in major shale units in northeastern British Columbia, Alberta, Quebec and New Brunswick. Early in 2010, one of the world's largest fracking operations to date was carried out northeast of Fort Nelson, British Columbia, in the Horn River Basin, by Houston-based Apache Corporation and Encana, making use of some 5.6 million barrels of surface water. Most of the water used in the fracking process water returns to the surface with the gas, creating the problem of what to do with the by-now heavily polluted water. Reinjection into the deep, saline groundwater bodies at depths of several kilometres is the current methodology, but many questions remain concerning the future fate of such water masses. Given the very high pressures being used, it is possible that the polluted groundwater could rise through fractures back to the surface, to pollute shallow groundwater or surface fresh water supplies.

Shale gas production has been underway for several years in Texas (Barnett Shale) and other areas of the United States, and no such incident of pollution has yet been proven, but opinions are currently divided regarding the overall environmental safety of the operations (Parfitt, 2010). An exploration program being carried out by Questerre Energy in the Utica Shale of the St. Lawrence Valley between Montreal and Quebec City came to a halt in October 2010 in part because of vocal expressions of public concern about potential pollution problems and possible discharge of natural gas into groundwater drinking supplies, and in part because of a lack of investment due to low gas prices brought on by the flood of shale gas onto the North American market. (McCarthy, 2010).

Regulation of surface water and groundwater use for shale gas operations has typically been removed from provincial and state environmental bodies and assigned to oil and gas regulators, a move that creates cause for concern, given the overriding mandate of such regulators to facilitate, even promote, resource extraction.

5.2 Contaminants of Emerging Concern (CECs)

Contaminants of emerging concern (CECs) refer to a complex spectrum of materials and organisms having potential significant impacts on human and environmental health. The development of better detection methods and a better understanding of the effects of materials (both natural and human-made) which permeate the environment have led to a new level of sophistication and complexity in health concerns.

The movements and reactions of CEC materials are influenced by the physical, chemical, biological and radiological systems, and as a result these materials may undergo changes in concentration, characteristics and reaction capability. CECs can be grouped by their characteristics (microbiological, organic chemicals, inorganic chemicals, physical parameters and radiological materials) or by their type of impacts (oxidation-reduction, acid-base, endocrine disruption, radiation, infections (microbial and prions) or cytotoxicity). The critical issue is what should be done to reduce the adverse impacts of these materials on the living and non-living components of the water world. This section examines some of the current issues and technologies that have been identified in Canada and, in some cases, used to reduce the impacts of CECs.

Types of CECs.

The general types of materials that are currently identified as being of concern to water systems include components from all aspects of human activities. As we learn more about the materials present and their interactions with each other and living things, the list will grow. Table 1 lists the general categories and subcategories

Table 1. General Categories of Contaminants of Emerging Concern

Category	Representative Sub-Category or Materials	Some Characteristics
Microbiological	Antibiotic resistant	Resistant to one or more antibiotics
	Prions	Misfolded protein molecules
	Microcystins	Natural and pollution driven growth of cyanobacteria
Organic Chemicals		
	Pharmaceuticals	Many classes of chemicals used by the medical profession to reduce health problems
	Phyto-estrogens	
	Hormones	Human and Animal
Society Targeted	Pesticides	A wide variety of chemicals used to kill selected or groups of living things
	Personal Care Products	Sunscreens, soaps, cleaning compounds
	Fire Retardants	Coatings, Sprays
	Surfactants	Reduce gas-liquid mass transfer
Industry Targeted	Solvents	Dissolve many materials
Inorganic Chemicals	Personal Care Products	Make-ups, cleaning compounds
	Gas Propellants	Aerosols and vapor transport from pressurized containers
	Hydrogen sulfide	Toxic effects, oxidizes to H_2SO_4
	Ammonia	
Physical Parameters	Particles - Air	PM10, PM2.5, lung penetration
	Particles - Water	Total Suspended Solids, reflection, refraction, adsorption, entrapment of CECs
Radiation	Ultraviolet light	Reactions in cellular materials which may lead to changes in actions

of CECs as well as some representative characteristics.

Sources of CECs.

All aspects of municipal, industrial and natural activities can release CECs into the environment. It is relevant to recognize that gas, liquid and solid phases of material can contain CECs. The transfer of a contaminant from one phase to another results in quality changes but does not reduce the contaminant load on the environment. The obvious example of this is volatilization or mass transfer from a liquid to a gas or vice versa.

Many studies of municipal wastewater (both raw and treated) have demonstrated that it contains materials (dissolved, solid or gaseous) identified in virtually all of the categories of CECs. In fact, virtually every human-made material can be found in municipal wastewater. As an example, a survey in Alberta identified 105 pharmaceuticals, hormones and endocrine disrupting compounds (EDC) in raw wastewater and 48 in treated effluent. A similar study in Ontario found similar results (Servos et al., 2005). Such surveys have been conducted around the world and all indicate that municipal wastewater carries all forms of CECs. Although the principal objective of wastewater treatment is to remove all contaminants from the raw wastewater, in reality only a few characteristic parameters are reduced.

Impacts.

Microorganisms are both allies and enemies of living things. Acaryotic (viruses), prokaryotic (bacteria and cyanobacteria), and eukaryotic (including the protists (algae, fungi and protoza)) and the metazoan (rotifers, nematodes) can have positive and negative relationships to other living things. Novel issues develop when humans introduce materials into the environment that accelerate changes in the microorganisms and, in some cases, make them more dangerous.

With respect to pharmaceuticals, the industry is continuously working to make them more resistant to degradation so that they will do their intended "jobs" better. As a result, it can be expected that their occurrence in wastewater and the difficulty of their removal will increase.

The discharge of conventionally treated municipal wastewater is now being shown to be problematic. Kerr et al. (2008) showed that conventional biological nutrient removal activated sludge treatment effluent and ultra-membrane filtered effluent did not reduce exposure to xenobiotics. However, additional treatment with activated carbon did reduce most xenobiotics.

Various other studies have been carried out investigating the effects of the different types of CECs found in Canada's water. A 2005-2006 survey detected trace levels of certain pharmaceuticals and BPA (Bisphenol A) in Ontario's untreated source water and finished drinking water sampled from various sources, but these are currently at levels that do not pose a threat to human health (Ontario Ministry of the Environment, 2006). Another study found that exposing fish to estrogen at levels similar to those found in many municipal wastewater effluents in Canada reduced egg production and male secondary sex characteristics (Parrott and Blunt, 2005). An investigation was conducted into the effect of commonly used agricultural pesticides on northern prairie wetlands, which found there to be no significant impact on the health of the water itself but these pesticides still pose a threat to aquatic life found in these wetlands (Johnson, 1986). Further CECs studies have been carried out regarding various types of pathogens in wastewater (Andersen, 1993; Bell et al., 1983; Finch and Smith, 1986) and waterborne disease (Neumann et al., 2005).

Management of CECs.

How can one manage the CEC materials? The answer is relatively simple: a multi-component program is required. First, there must be legislation and the related regulations with enforcement support to prevent production where possible, reduce discharge, and educate people with respect to proper handling procedures.

Control of CECs requires at least three simultaneous types of actions: a) stop the creation of CECs; b) control the disposal of CECs, and c) destroy or change them into non-dangerous materials. All three approaches require very important action at the government level – the enactment of legislation and regulations to empower each type of enforcement.

5.3 Brownfields

The Environmental Protection Agency defines brownfield sites as "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant" (US EPA, 2005). In Canada, the National Roundtable on the Environment and the Economy (NRTEE, 2003) states that "Brownfields are the legacy of a century of industrialization – they are abandoned, idle or underutilized commercial or industrial properties where past actions have caused known or suspected environmental contamination, but where there is an active potential for redevelopment". In fact, brownfields exist in very large numbers and pose serious environmental and health risks in industrialized countries around the world.

For instance, the United States is thought to contain between 500,000 and 1,000,000 brownfield locations while Germany about 362,000 (NRTEE, 2003). Canada may possess up to 30,000 brownfields, including the sites of almost-forgotten industrial enterprises such as coal gasification plants, locations where toxic substances were used or stored, and former gas stations and mining operations (De Sousa, 2001). Brownfields currently being created on a large scale include the oil sands development in Canada (Section 4.3) and the rapidly expanding industrial sites in China and India for which massive economic growth is of paramount importance at the expense of extensive environmental degradation. By definition, brownfields almost always result in the contamination of ground and/or surface water resources, and sometimes the atmosphere.

Brownfield redevelopment consists of two main stages: remediation of the contaminated land and subsequent utilization of the site for a range of development purposes such as the building of commercial, educational and residential facilities. Fortunately, the restoration of brownfield sites furnishes a variety of economic, social, and environmental benefits to stakeholders (NRTEE, 2003). From an economic perspective, brownfield redevelopment has a total output multiplier of 3.8 (NRTEE, 2003) and provides economic benefits which include the development of exportable restoration technologies, provision of an expanded tax base for all levels of government, and creation of employment opportunities. From a social viewpoint, brownfield restoration can enhance quality of life, eliminate health threats, and furnish land for affordable housing. Finally, environmental benefits of brownfield restoration include restoration of environmental quality, prevention of the further contamination of water supplies for municipalities, and reduction of expansion pressure from urban centers into surrounding greenfields. Within Canada, many municipalities have ambitious brownfield programs for enticing land owners and developers to restore and develop brownfields, with both economic and legislative support from their provincial governments. Bernath Walker et al. (2010), for example, carry out a strategic analysis of the successful negotiations that took place over the over the renovation of the former Kaufman Footwear manufacturing facility in downtown Kitchener, Ontario, into residential lofts at this former brownfield site. Hipel et al. (2010) present a systems methodology for resolving both the strategic and tactical aspects of complex brownfield conflicts and stress the role that positive attitudes can play in reaching win/win outcomes for the stakeholders.

An especially contentious brownfield conflict in Canada has been over the tar ponds in Sydney, Nova Scotia. The tar ponds are one of the most toxic sites in Canada, resulting from a century of steel and coke production. Contaminants from the production polluted the soil on the site and were carried by a stream into two large pools of sludge, which now contain 700 thousand tonnes of chemicals including PCBs (CBC News, 2004). Reports of deleterious effects of the tar ponds by nearby residents and environmental groups have been repeatedly dismissed by government-sponsored investigations, but a 2003 study found there to be an exceptionally high cancer rate in the surrounding communities. Two failed attempts have been made to clean up the site in the past 20 years (CBC News, 2007). The federal and provincial governments are currently funding a controversial project to solidify and stabilize the contaminants by mixing the material with concrete, which is scheduled for completion in 2014 (Top 100: Canada's Biggest Infrastructure Projects, 2009).

5.4 Bottled Water

The bottled water industry represents a triumph of commercial promotion over common sense. Municipal tap water in most of the developed world is processed to a high state of purity and taste, and is entirely acceptable for human consumption. However, almost a third of Canadian households have been persuaded otherwise by the advertising for bottled water (Sandford, 2007; Lem, 2008). In fact, testing standards for bottled water are lax and erratic. Bottled water is regulated at the federal level by Health Canada and the Canadian Food Inspection Agency, and provinces and territories can impose additional regulations (Health Canada, 2009). Whereas the quality of Canadian municipal water is monitored daily, bottled water is only tested every three years (CBC News, 2008). Moreover, bottled water companies are not required to share their water test results with the public (CTV News, 2006). Additionally, unlike municipal water in Canada, most brands of bottled water do not contain fluoride, a proven agent for the prevention of tooth decay (CBC News, 2008).

Canadian researchers have found that some bottled water in Canada contains harmful levels of bacteria. However, Health Canada has not set an allowable bacteria-level limit for bottled water (Cross, 2010). The plastic used for bottled water represents a significant use of petrochemical feedstock. Although bottled water containers are recyclable, a large proportion of used containers end up in landfills, as much as 80% in some communities (Council of Canadians, 2008). Consequently, disposal of the bottles has become a major issue, with some jurisdictions (e.g., London, Ontario) reporting a significant increase in volume, coupled with a reduction in weight, of city garbage, as a result of the huge increase in waste bottles. A visit to any North American or European coastline will reveal numbers of bottles washed up on the beach – another serious sign of unmanaged waste. Moreover, the production and transportation of bottled water uses vast amounts of fossil fuels and water, and produces significant amounts of greenhouse gases. The Pacific Institute has estimated that the bottled water produced worldwide in 2006 for American consumers required more than 17 million barrels of oil (not including transportation energy), which produced more than 2.5 million tons of CO_2, and that every litre of bottled water required 3 L of water for its production.

Due to loopholes in Canadian law, bottled water is a means by which water is being exported out of the country. Since water is regarded as a commodity when it has been bottled and bulk water bans only apply to containers greater than 20 L, there is no limit to the amount of bottled water that can be exported out of Canada (Rinehart, 2007). Consequently, Canada has become a net exporter of bottled water, with the profits largely going to foreign-owned, multinational water companies. These companies are threatening entire watersheds in Canada by their extraction of water from springs and aquifers that have not been properly evaluated, and they are charged very little for this water (Barlow, 2007). There have been reports of water shortages in the Great Lakes region close to water bottling plants, according to the Earth Policy Institute (Council of Canadians, 2008).

On account of the foregoing issues with bottled water, there has been a growing movement in Canada against bottled water. Thirty municipalities from 7 provinces have taken significant actions against bottled water, such as banning the sale of it at municipal facilities, and 21 universities and colleges have created "bottled water free zones" (Polaris Institute, 2009).

5.5 Climate Change

Kathy Jacobs, Executive Director of the Arizona Water Institute, has referred to water as "the delivery mechanism for the impacts of climate change". That is, the effects of climate change will be most readily experienced through changes in water (Brubaker, 2009). Below is a short description of the impending challenges and opportunities posed by climate change with respect to water for the different regions of Canada, followed by a brief explanation of actions that can be taken to address this issue.

The effects of climate change in Canada have thus far been most dramatically apparent in the Arctic, and polar regions of the world are forecasted to undergo the most extreme weather pattern disruptions in the future (McCarthy, 2010). The melting of Arctic sea ice has greatly accelerated in the past decade. Approximately 2 million km^2 of sea ice melted from 2000 to 2010, compared with a loss of less than 1 million km^2 in the previous two decades (Simpson, 2010). In fact, the Canadian Arctic experienced its lowest recorded summer ice extent in 2010 (McCarthy, 2010). The ice cover is also thinning (NRCan, 2007). The opening of the Arctic sea will allow greater opportunities for shipping and tourism, but will disrupt the ecology of the region (Canadian Geographic, 2010a). Furthermore, as warming causes Arctic permafrost to melt, drinking water and sewage lines will become ruptured (NRCan, 2007). Another result of permafrost degradation that is already being experienced is the loss of vast areas of boreal forest, the importance of which was discussed in Section 4.3.

Another consequence of climate change is the increased frequency of high-intensity precipation which can wash nutrients, toxins and pathogens into water bodies as well as cause flash floods in small watersheds and urban areas. In Atlantic Canada, an increase in the number and intensity of storms, in combination with elevated sea levels, is expected to cause flooding and erosion along coastal areas and rivers (Richardson, 2010; Bruce et al., 2000), which may lead to the spread of waterborne pathogens and saltwater intrusion into groundwater aquifers (NRCan, 2007). Moreover, the loss of ice cover may make coastal regions more susceptible to erosion (Canadian Geographic, 2010a).

Riverine flooding due to increased precipitation and loss of ice is also a major concern for Quebec. This may result in sewer overflows, which can contaminate municipal water supply systems (Bruce et al., 2000). As discussed in Section 4.6, hydroelectricity is the dominant form of electrical power in Quebec. Quebec's hydroelectric generation stands to either benefit or suffer from climate change. Additional water in northern Quebec and in Labrador may boost the electrical generation of the James Bay Project and the Churchill Falls Station, respectively, but these gains may be offset on account of the lower flow of the St. Lawrence River, which would affect the Beauharnois and the Les Cèdres power plants dependent on this source (Bruce et al., 2000). The lowering of the water levels of the St. Lawrence would also impact navigation, marinas, municipal water supplies, wetlands and fisheries (Tar Sands Watch, 2008).

The water levels of the Great Lakes (Section 4.5), which are surrounded by 40 million people, have been predicted to decrease by 24% in the event of a 2 to 4% increase in temperature (Tar Sands Watch, 2008), although a recent study by the IJC found that there may be a more modest drop in water levels (Kart, 2010). Moreover, historical data show significant fluctuations in lake levels over decadal periods, indicating that natural regional climate oscillations are also likely an important factor in environmental change (Fisheries and Oceans Canada, 2007).

A significant reduction in water levels would place stresses on navigation, municipal water supplies, hydroelectric generation, recreation and ecosystems (NRCan, 2007). Furthermore, the combined effects of reduced water levels and increased demand in the Great Lakes, as well as in other regions throughout southern Canada, by 2050 will "evoke conflicts among water users and place strains on boundary and transboundary water agreements" (Canadian Geographic, 2010a). A reduction in water quantity also entails a reduction in water quality, as pollutants will be more concentrated and settled (NRCan, 2007). Additionally, Great Lakes ice cover has shown a declining trend over the past thirty years, which causes greater evaporation and thus lower lake levels and also has other economic and ecological implications (International Upper Great Lakes Study, 2009; Wang et al., 2009).

Climate change issues affecting the Prairie Provinces have been discussed in Sections 4.1 and 4.2. Land at risk of desertification in the Prairies is expected to increase by 50% by 2050 and the frequency of droughts lasting four to six months could double (Canadian Geographic, 2010a). On the other hand, there is the prospect that arable land will expand northward (Bruce et al., 2000). Similar to the Atlantic Provinces, British Columbia faces the threat of more frequent high-intensity rains and coastal and riverine flooding, potentially leading to waterborne health effects and saltwater intrusions into water supplies (Richardson, 2010; NRCan, 2007). River flows will become lower in southern British Columbia, placing strains on agriculture and municipal water supplies, but somewhat greater flows are expected in the north (Bruce et al., 2000).

In light of the impending drastic changes to Canada brought about by climate change, Bruce et al. (2000) urge the country's leaders to act now to prepare for this inevitability, as it may be much more costly and less effective to react to the challenges as they arise at the last moment rather than preparing beforehand and the necessary adaptations for dealing with climate change are also needed for improving Canada's present situation. They recommend the following courses of action for adapting to climate change: creating a national strategy for water resources and climate change; establishing a mechanism for inter-agency coordination at the federal level, as well as a mechanism for federal-provincial and multi-stakeholder coordination, to facilitate the development and implementation of the strategy; implementing further research to guide the strategy; enlisting the collaboration of existing agencies in developing the strategy; and organizing a national conference on water resources and climate change to raise awareness and set the agenda for the strategy. The National Research Council of the National Academy of Sciences (2010a, b, c, d) has likewise put forward national climate strategies for the US.

There has been some degree of progress amongst Canada's politicians in taking steps towards addressing the effects of climate change. For instance, progress was made during the 2010 meeting of the premiers of the provinces and territories in Western and Northern Canada at the annual Western Premiers' Conference on June 15th and 16th. During the first day of the conference, the leaders discussed the significance of climate change and its impact on water resources, agreeing to a Water Charter making protection of this resource a priority (Crawford, 2010). However, Maude Barlow, National Chairperson of the Council of Canadians, is of the persuasion shared by many others, that political leaders cannot be counted on to carry out the substantial undertakings that are necessary for adapting to climate change unless there exists a widespread public movement in this direction. Accordingly, scientists have the responsibility of conveying the implications of climate change to the public in an effective manner (CBC Ideas, 2010). Homer-Dixon (2006) believes that catastrophes connected to climate change are needed to spur society to take meaningful mitigative action to significantly reduce greenhouse gas emissions and adapt to the effects of climate change.

In fact, geoengineering, which consists of utilizing carbon dioxide removal and solar radiation management technologies for intentionally altering the climate system on a large scale, may be required to stave off severe climate change (Blackstock and Long, 2010). Homer-Dixon (2009) has referred to this dramatic geoengineering intervention process as "Plan Z". Clearly, climate change will have adverse impacts on the hydrological cycle depicted in FIG. 3. The failure to respond responsibly to climate change challenges has ethical and moral implications (Gardiner, 2011). Implementation of climate change strategies may take place at the municipal (Richardson, 2010) and basin levels (Section 3.3), but effective policies are also required at the provincial, national (Section 3.1) and international levels (Sections 3.2 and 3.5).

6. Recommendations for Alleviating Canada's Strategic Water Problems

As explained in Section 6.1, Canada has a timely opportunity to display real leadership with respect to pursuing meaningful innovations in water governance. In particular, Canada can adopt the systems-thinking approach described in Section 6.2 to implement the range of water policy recommendations put forward in Sections 6.3.1 and 6.3.2 for enhancing water governance within Canada and internationally, respectively. A good place to start is to develop a comprehensive national water policy in cooperation with the ten provincial and three territorial governments, while simultaneously encouraging other water initiatives for solving pressing problems. The time to begin was yesterday.

6.1 Opportunity for Meaningful Change

As illustrated in Section 4, Canada faces a wide range of daunting regional water challenges stretching from British Columbia eastwards to the Atlantic border northwards to the Arctic. Moreover, as explained in Section 5, common types of formidable water problems exist within many regions of Canada. Over the years, Canada has certainly established an enviable record in many areas of water resources management. For instance, virtually every community across the entire country has access to clean water, although small aboriginal communities are a notable exception to this accomplishment. The federal government recently introduced a regulation mandating minimum sewage treatment standards on every wastewater facility in Canada. Municipalities will be given 10 to 30 years to comply, however, but this is at least a step in the right direction (Weston, 2010). On November 30, 2010, the Ontario Legislature passed the Water Opportunities and Water Conservation Act, which aims to make the province a leader in clean water services and technologies via the joint effort of industry, academics and government, as well as to support its citizens in using water more efficiently and to facilitate more sustainable municipal water planning (Business Wire, 2010). In many parts of the country, good water governance exists at the basin level. For instance, as pointed out in Section 3.9, under the Quebec Water Policy adopted in November 2002, basin organizations were established for 33 major watercourses to promote sustainable development via an integrated water resources management approach. As noted in Sections 3.3 and 4.5, Canada and the United States have cooperated in better managing the valuable water resources of the Great Lakes through the Boundary Water Treaty of 1909 and extensions thereof. Nonetheless, much remains to be done to enhance water governance within Canada and internationally, especially with the United States.

The world is currently experiencing a range of highly interconnected crises. In the midst of the worst recession since the Great Depression of the 1930s, climate change, overpopulation, overconsumption and other associated factors, are putting enormous pressure on the availability of freshwater supplies to meet human needs in a sustainable manner (Brown, 2011). By altering climate, FIG. 3 shows how the water cycle can be adversely affected by greenhouse gas emissions. However, difficult times provide fertile soil for growing rich crops of real and meaningful change. In the next section, the solid foundations upon which effective water governance can be based are described. In particular, a system thinking methodology for water governance is proposed in which an integrative and adaptive approach is employed within an overall system of systems framework. Subsequently, within the realm of a system of systems philosophy, specific recommendations are formulated in Section 6.3 for enhancing water governance at all levels of government within Canada as well as in the international arena.

6.2 Systems Thinking in Water Governance

The world in which we live consists of complex highly interconnected systems of systems (SoS). Examples of societal SoS include economical, political, agricultural, industrial, infrastructure, and urban SoS. Illustrations of environmental SoS are hydrological (FIG. 3), atmospheric, botanical, zoological, ecological and geological SoS. In fact, most of today's pressing large-scale problems facing humanity, such as scarcity of freshwater, global warming, energy shortages, overpopulation, widespread pollution, the food crisis and economic disparities, can best be envisioned and understood as complex adaptive systems problems which are tightly interconnected and thereby affect one another in synergetic and often unexpected ways, referred to as emergent properties (Homer-Dixon, 2006; Hipel and Fang, 2005; Hipel et al., 2008b, 2009).

For instance, global warming can cause climate change which may create water shortages, which in turn adversely affect the economy and people's welfare via decreased agricultural and industrial productivity. Accordingly, water governance within Canada and abroad must be founded upon the basic paradigm of SoS thinking in order to meet key systems principles such as resilience, sustainability and fairness (Hipel et al., 2008a, b, 2009; Simonovic, 2009, 2011). Of course, appropriate ideas from economics, sociology, the humanities, science, engineering and mathematics may be utilized within this overall SoS framework for serving society and preserving the environment.

Fortunately, researchers and practitioners working within the field of water resources are pioneers in the development and application of systems thinking for addressing complex water problems. Two important and interrelated concepts required for achieving effective water governance within a SoS framework are integrative and adaptive management. As defined in "A handbook for Integrated Water Resources Management in Basins" published in 2009 by the Global Water Partnership (GWP) and International Network of Basin Organizations (INBO) (2009), "The integrated water resources management approach helps to manage and develop water resources in a sustainable and balanced way, taking account of social, economic and environmental interests. It recognizes the many different and competing interest groups, the sectors that use and abuse water, and the needs of the environment".
Notice that this systems thinking approach to water resources management acknowledges that many interconnected factors must be considered and that the value systems of competing stakeholders and environmental requirements must be taken into account.

Furthermore, because of the physical reality that a watershed controls the flow of water, the most important management practices must be implemented at the basin level (Section 3.3 and (FIG. 3) in consonance with policy, laws and regulations at the local, regional, provincial or state, national and international levels. For example, the International Joint Commission (2009) (Section 3.2) has suggested an integrated approach to river basin management for basins that are intersected by the Canada-US border. In its Managua Declaration, IANAS (2009) declared that all countries in North and South America "should improve the way in which water is managed in order to perform it in a more integrated and sustainable way".

Besides being integrative, water governance must be adaptive in order to handle the largely unpredictable behaviour of environmental and societal SoS brought about by their intrinsic complexity, uncertainty and interconnectedness. Because of this unpredictability, one never knows in advance how well a given plan or policy is going to work for appropriately addressing anticipated or unexpected events. Under passive adaptive management, one employs new knowledge gained by monitoring and experience to iteratively update models or plans to improve existing management approaches and associated decision making. When pursuing active adaptive management, plans or strategies are purposefully altered in order to scientifically test new hypotheses, and thereby learn by experimentation to ascertain the best management strategy. Accordingly, adaptive management is popularly referred to as "learning by doing". The concept of adaptive management was originally proposed by Holling (1978) and other scientists as a consequence of studying resiliency theories of ecological systems, and since that time a rich body of literature has accumulated including contributions by Walters (1986), National Research Council (2004), Noble (2004), Gunderson and Holling (2002), Gunderson and Light (2006), American Water Resources Association (2006, 2009), Williams et al. (2007) and Heathcote (2010).

In practice, one can employ both integrated and adaptive management approaches in water governance, as is recommended by many of the organizations and research groups whose websites are listed at the end of this report. In fact, ideas from adaptive management are contained within the aforementioned handbook on integrative water resources management (GWP and INBO, 2009). This valuable handbook presents detailed explanations as to how integrated water resources management can be actually implemented and uses case studies from around the globe to illustrate how this is done according to key issues such as financing, stakeholder investment, and basin information systems and monitoring.

As mentioned in Section 4.5, the adoption of adaptive management is encouraged within the Great Lakes-St. Lawrence River Basin Water Resources Compact of December 13, 2005. Hipel et al. (2008b, 2009) recommend that adaptive integrative management be conducted within a SoS framework coupled with the employment of formal decision-making tool, from operational research, systems engineering and other systems science fields, as well as ideas from the social sciences and humanities. Moreover, any policy or agreement should reflect the value systems of the stakeholders it serves and contain a dispute resolution mechanism that guides disputants in a positive direction towards a win/win resolution. Using concepts from hydrology, economics, cooperative game theory and ethics, formal methods have been developed for fairly allocating water among competing uses in a river basin (Wang et al., 2008). When made available as decision support systems, decision aides from the systems sciences permit practitioners to tackle complex real world problems arising in water governance and elsewhere.

6.3 Specific Recommendations for Enhanced Water Governance in Canada and at the International Level

Water scarcity is usually caused by the ineffective management of water rather than by lack of availability alone. Accordingly, the prevailing global water crisis is more akin to a "crisis of governance" than a "pure resource crisis" (Ng and Felder, 2010; Saleth, 2010). As stated in the Freshwater Declaration of Pugwash (2008), "strong and enlightened governance" is required in order to have healthy, functioning freshwater ecosystems. Particular ways in which Canada should "get its own house in order" with respect to water governance and associated issues, are presented in the next subsection. Subsequently, specific suggestions are put forward as to how Canada should enhance and expand international agreements with other countries that are in consonance with Canadian values and objectives in a range of interconnected issues which includes water governance. Finally, over the years, numerous authors and organizations have put forward suggestions for improving water governance in Canada and elsewhere. For example, many of the authors of papers listed in the reference section, such as Bruce and Mitchell (1995) and de Loë (2009), as well as most of the organizations whose websites are given in Section 7.1, have proposed a rich range of water policy recommendations. As would be expected, many of these suggestions overlap with those given below.

6.3.1 Water Governance Enhancements within Canada

Recommendation 1. Systems Philosophy: All levels of government in Canada should adopt an adaptive, integrative and participatory approach to water governance within the framework of the paradigm of a system of systems as the foundation upon which they will improve and expand water governance which includes policy, laws, agreements, compliance, institutions and management.

As noted in Section 3.2, the Federal Water Policy was tabled in 1987. To overcome the drawback inherent in this policy as well as the realities of changes that have taken place since 1987, the next recommendation is proposed.

Recommendation 2. National Water Policy: In consultation with all levels of government and key stakeholders, Canada should develop a comprehensive national water policy that reflects the values of Canadians and is in consonance with the legislative power of all levels of government and follows the philosophy of Recommendation 1.

Comments: Various Canadian organizations have put forward this recommendation, including Pollution Probe (2007), Pugwash (2008), Gordon Water Group (2008) and the Canadian Water Resources Association (CWRA) (de Loë, 2008). An overarching water strategy would provide numerous benefits to Canada, such as increased effectiveness, efficiency and consistency in water management and responses to national water concerns, and would be in line with the path taken by other jurisdictions, such as Brazil, Australia, South Africa and the European Union (de Loë, 2008). The establishment of a national water policy need not entail the oversight of a large, centralized bureaucracy, but should rather be integrated within existing structures and should be applied strategically to only those areas in which Canada would stand to benefit from joint actions of the various jurisdictions throughout the country (de Loë, 2009).

Recommendation 3. Governance Structures: Develop policy and other associated governance structures for fairly and effectively sharing water among competing users within a water basin.

Comments: Fairness in water governance is of high importance in regions of Canada where droughts and associated water shortages occur such as in the Prairie Provinces, as discussed in Section 4.2. Some systems approaches have been developed for addressing the perplexing problem of fair allocation of resources. In particular, based on concepts from hydrology, economics and cooperative game theory, Wang et al. (2008) developed the Cooperative Water Allocation Model (CWAM) within the framework of a large-scale optimization program for equitably allocating water following two main steps. Firstly, water is allocated among users based on existing legal water rights regimes or agreements. Secondly, water and associated benefits are reallocated among stakeholders to maximize basin-wide welfare. CWAM has been applied to the South Saskatchewan River Basin in Alberta to demonstrate how it can be conveniently applied to a water allocation system of systems problem.

Bakker (2007) points out that there exists a great diversity of approaches to water governance in municipalities throughout Canada, and that other countries have adopted a combination of different models. A factor of key importance in choosing a form of water governance is for the public to be well informed and to be afforded a robust participation in the process (Horbulyk, 2007; Christensen and Lintner, 2007).

The extraction, use and disposal of surface waters and groundwaters by the energy industries (in particular, shale gas and oil sands) should not be left to the management of oil and gas regulators, but subject to appropriate environmental oversight. Minimum in-flow needs and pollution issues have received very inadequate management in Canada because of the inaction of both provincial and federal authorities to make these issues a priority. For these and other reasons an energy strategy of Canada is given as Recommendation 7 below.

Recommendation 4. Water Use Efficiency: Enhance and promote efficiencies in water use by the introduction of new industrial, agricultural and domestic technologies. Realistic pricing of water supplies would help to enhance efficiencies.

Recommendation 5. Monitoring and Analysis: Expand and enhance analysis and monitoring programs within key water sources (major rivers and lakes), and continue and expand the application of modern hydrological, hydrogeogical and geological analysis of groundwater systems. Developing databases utilizing the concepts and methods of modern Geographic Information Systems would vastly increase the efficiency and utility of this work.

Comments: In Canada, there needs to be much better coordination of monitoring and regulation between the provinces and the federal government. Legislative mandates that partially overlap, including those for regulating water use, the transport and deposition of deleterious substances, and the health of fisheries, should not be a barrier to the development of shared management practices and licensing procedures.

Recommendation 6. Canadian Greenhouse Gas Reductions: Canada should immediately put in place meaningful greenhouse gas reductions in cooperation with the provincial and territorial governments.

Comments: Canada should be imaginative in putting together greenhouse gas reduction programs. For instance, it could assist Alberta in reducing greenhouse gas releases in the oil sands by promoting the building of new Canadian-Designed Advanced CANDU Nuclear Reactors to supply energy to the oil sands industry. The construction of CANDU reactors to service energy market demands in other parts of Canada and abroad would be a clever way for Canada to use its well-established nuclear industry for environmental protection and furnishing jobs and wealth for Canadians (Hipel and Bowman, 2011). In fact, the strong interconnections among energy, the environment, water, the economy and society lead to the next recommendation.

Recommendation 7. Energy Strategy for Canada: The Federal Government of Canada should develop a comprehensive national energy policy, based on sound systems principles, in collaboration with provincial, territorial and First Nations governments, as well as industrial, agricultural, environmental and other appropriate stakeholders.

Comments: A sound energy strategy is a necessary condition for having effective environmental and water policies (Miall, 2011). Because of its massive energy resources and well-established expertise in many energy fields, Canada is in a particularly strong position to positively influence governance of water and the environment both at home and abroad via the development of a bold and integrative energy strategy. On numerous occasions, Canadian Prime Minister Stephen Harper has stated the Canada is an 'emerging energy superpower'. To realize this vision, however, Canada must manage energy as an integrated system, not as the isolated development of specific energy sources. Canada needs to have a national energy strategy that straddles the full spectrum of nuclear, fossil fuel and renewable resources. To be a sustainable energy superpower, none of these 'legs' can be neglected. Additionally, the electric power produced from these resources should be interconnected across the nation (Hipel and Bowman, 2011).

All of Canada's energy resources, not to mention its other vast array of natural resources, should be fully developed and processed within Canada such that these extensive "value-added" economic activities create real wealth and meaningful employment for Canadians. For example, as pointed out in Section 4.3, 30% of unprocessed bitumen is being shipped outside of Canada for upgrading and this figure could rise to 50% by 2019.

This type of gross mismanagement should not be tolerated by Albertans, in particular, or by Canadians, in general. The full processing of bitumen to produce a rich range of oil products should be done by refineries located within Canada for selling to both domestic and foreign markets. A valuable spinoff of keeping all aspects of oil production within Canada could be the development of home-grown environmental technologies to minimize the pollution of surface water, aquifers and the atmosphere. In addition, fewer pipelines would be needed for shipping relatively large quantities of unprocessed bitumen to the United States, thereby reducing the risk of pipeline breaks such as the ones that have recently occurred in Little Buffalo, Alberta (May 2011) (Wingrove, 2011) and in Michigan, USA (July 2010) (Reuters, 2010).

Fortunately, responsible and innovative roadmaps charting the ways by which Canada could become a sustainable energy superpower have already been documented and further investigations are underway. In particular, within the Energy Pathways Project of the Canadian Academy of Engineering, Canada´s foremost engineers have evaluated a wide range of energy scenarios for Canada according to technological, environmental, social and economic criteria (Bowman and

Griesback, 2009; Bowman et al., 2009, website of the Canadian Academy of Engineering listed in Section 7). Under the Trottier Energy Futures Project (sponsored by the Trottier Family Foundation), the Canadian Academy of Engineering and the David Suzuki Foundation are jointly investigating energy challenges for Canada in the 21st century in terms of supply, environmental sustainability, climate change and economics (websites for the Canadian Academy of Engineering and the Trottier Energy Futures Project listed in Section 7.1). In 2003, the Royal Society of Canada held a one-day symposium entitled "Energy, Environment and Society: Making Choices" under the leadership of A. Miall. Progress on energy research and implementation of technologies across Canada has been tabulated by the Canadian Academy of Engineering (Bowman and Albion, 2009).

6.3.2 Water Governance Improvements at the International Level

Recommendation 8. Responsible International Economic Agreement: Canada should negotiate an international economic agreement that prioritizes the maintenance of a healthy environment, societal well-being and the rights of individuals within a sustainable development structure and adhering to the systems principles of Recommendation 1 of Section 6.3.1.

Comments: This comprehensive agreement may consist of radically revised WTO and NAFTA agreements or a completely new encompassing agreement (Section 3.5).

Recommendation 9. Greenhouse Gas Emissions Agreement: Canada should immediately negotiate a meaningful greenhouse gas agreement with all the nations of the world to dramatically reduce greenhouse gas releases. However, this should be done within the context of an integrative agreement on the control and management of air pollution in general based on a sound systems philosophy (Recommendation 1 and Section 6.2).

Comments: These negotiations may constitute a continuation of the Copenhagen process or a fresh track of negotiations. The resulting treaty would help to maintain the integrity of the hydrological cycle in Figure FIG. 3. The terms of the treaty should be based upon solid systems principles. As pointed out by Hansen (2009), for example, a range of "climate forcings" created by human activities can increase the global temperature, while others can lower atmospheric temperatures.

Accordingly, an innovative treaty can cleverly manage these forcings brought about by industrial, agricultural and other human enterprises to reduce temperature. For instance, in the short term, the treaty could cut back on the release of black soot, methane and ozone close to ground level to lessen temperature in order to allow more time for carbon dioxide releases to be cut back over time. Moreover, the reduction of air pollutants that cause temperature to decrease via reflective aerosols and aerosol cloud changes could be curtailed until temperature-increasing air pollutants are brought under control.

Additionally, because this air pollution treaty would be integrative and adaptive, appropriate measures could be taken over time as dictated by scientific evidence and in response to unexpected emergent behaviour of the atmosphere and perhaps also the oceans. In other words, society is responsible for initiating actions to deal with the situations as they occur and reduce and manage negative impacts that may develop. Finally, the "precautionary principle" (SEHN, 1998) could be adhered to until sufficient data and scientific knowledge are available (Section 4.7 for a discussion of the precautionary principle with respect to bulk water exports and water diversions). For example, greenhouse gas reductions should be pursued within a treaty until sound scientific evidence dictates otherwise. If, for instance, temperature starts to spiral out of control, the treaty should have provisions for the responsible employment of geoengineering techniques (Section 4.5, as well as Homer-Dixon [2009], and Blackstock and Long [2010] and references contained therein).

Recommendation 10. Global Water Treaty: Canada should lead the world in drawing up a comprehensive international treaty for freshwater following the systems ideas of Recommendation 1 of Section 6.3.1.

Comments: This treaty may be done in conjunction or parallel with Recommendations 8 and 9. Since freshwater is less of an interconnected global resource than the atmosphere, this treaty may be even more difficult to achieve than a greenhouse gas emissions agreement.

7. Websites

Most of Canada's universities have significant programs in the teaching and execution of research in water resources. Because one must consider both the societal and physical systems aspects of water resources, the theory and practice of water is highly interdisciplinary and water experts can be found in almost all faculties at universities.

For this reason, researchers and practitioners working in the water field were among the first people outside of the military to adopt and expand the employment of a systems-thinking approach (Section 6.2) to address tough water problems using systems tools created initially in the fields of operational research and systems engineering during and after World War II (Hipel et al., 2008a, b). Very unfortunately, over the past three decades all levels of government in Canada have generally cut back on the amount of resources devoted to water and the environment within governmental agencies, although useful material may be found at some websites. Informative websites, mainly created in Canada, where one can find excellent information and research results involving topics connected to water are listed in Section 8. Because of the enormity of research regarding water carried out in Canada, only a representative list of references are furnished in Section 6.2 as background material to the topics covered in this report.

1. 2010 Annual Conference of the McGill Institute for the Study of Canada: "Canadian Water: Towards a New Strategy," http://www.mcgill.ca/water2010/
2. Alberta WaterSMART, http://www.albertawatersmart.com/index.html
3. Canadian Academy of Engineering (CAE), http://www.acad-eng-gen.ca/e/home_.cfm
4. Canadian Council of Ministers of the Environment (CCME), http://www.ccme.ca/

5. Canadian Water Network (CWN), http://www.cwn-rce.ca/
6. Canadian Water Resources Association (CWRA), http://www.cwra.org/
7. Centre for International Governance Innovation (CIGI), http://www.cigionline.org/
8. Conflict Analysis Group, http://www.systems.uwaterloo.ca/Research/CAG/
9. Council of Canadians, http://www.canadians.org/
10. Council of Canadian Academies, http://www.scienceadvice.ca/en.aspx
11. David Suzuki Foundation, http://www.davidsuzuki.org/
12. Environment Canada, http://www.ec.gc.ca/
13. Forum for Leadership on Water (FLOW), http://www.flowcanada.org/
14. Geological Survey of Canada (GSC), http://gsc.nrcan.gc.ca/index_e.php
15. Global Water Partnership (GWP), http://www.gwpforum.org/
16. Gordon Water Group, http://www.gordonwatergroup.ca/
17. International Joint Commission (IJC), http://www.ijc.org/
18. International Network of Basin Organizations (INBO), http://inbonews.org/
19. National Round Table on the Environment and the Economy, http://www.nrtee-trnee.com/
20. Natural Resources Canada (NRCan), http://www.nrcan.gc.ca/com/index-eng.php
21. One Drop Foundation, http://www.onedrop.org/en.aspx
22. Pembina Institute, http://www.pembina.org/
23. Pollution Probe, http://www.pollutionprobe.org/
24. Program on Water Issues (POWI), Munk School of Global Affairs, http://powi.ca/
25. Pugwash, http://www.pugwash.org/
26. RBC Bluewater Project, http://bluewater.rbc.com/
27. Rosenberg International Forum on Water Policy, http://rosenberg.ucanr.org/
28. Royal Society of Canada, http://www.rsc.ca/
29. Trottier Energy Futures Project (Projet Trottier pour l'Avenir Énergétique), http://www.trottierenergyfutures.ca/
30. Walter & Duncan Gordon Foundation, http://www.wdgf.ca/
31. Water Institute, University of Waterloo, http://water.uwaterloo.ca/

8. References

1. 2003 International Year of Freshwater, "`Virtual Water," 2003. Available at http://www.wateryear2003.org/en/ev.php-URL_ID=5868&URL_DO=DO_TOPIC&URL_SECTION=201.html. Accessed on September 26, 2010.
2. Academic dictionaries and encyclopedias, "James Bay Project." Available at http://en.academic.ru/dic.nsf/enwiki/405323. Accessed on October 24, 2010.
3. Alberta Environment, "Specified Gas Reporting Regulation: Alberta Environment Report on 2007 Greenhouse Gas Emission," Edmonton, Alberta, 2008.
4. Alberta Environment. "Towards Environmental sustainability, Proposed Regulatory Framework for Managing Environmental Cumulative Effects." Government of Alberta, 21 pp., 2007.
5. American Water Resources Association (AWRA), "Adaptive Management of Water Resources," Water Resources Impact, Vol. 8, No. 3, May 2006.
6. American Water Resources Association

(AWRA), "American Water Resources Association Summer Specialty Conference 2009: Adaptive Management of Water Resources II," proceedings of a meeting held 29 June - 1 July 2009, Snowbird, Utah, Curran Associates, Inc., October 2009.

7. Andersen, S. R., "Effects of waste-water treatment on the species composition and antibiotic-resistance of coliform bacteria. Current Microbiology," Vol. 26, No. 2, pp. 97-103, 1993.
8. Armin, M., "Energy Strategies of the Canadian Province of Ontario," Master's Thesis, University of Waterloo, Waterloo, Canada, 2010.
9. Bakker, K., "Commons or Commodity? The Debate over Private Sector Involvement in Water Supply," in Bakker, K. (Editor), "Eau Canada: The Future of Canada's Water", University of British Columbia Press, Vancouver, British Columbia, Canada, 2007.
10. Barlow, M., "Blue Covenant: The Global Waters Crisis and the Coming Battle for the Right to Water," McClelland and Stewart, Toronto, Ontario, Canada, 2007.
11. Barlow, M., "What You Don't Know About a Deal You Haven't Heard Of," The Globe and Mail, January 6, 2011.
12. Barlow, M. and Clarke, T., "Blue Gold: The Battle Against Corporate Theft of the World's Water," Stoddart, Toronto, Ontario, Canada, 2002.
13. Bell, J. B., Elliott, G. E. and Smith, D. W., "Influence of sewage treatment and urbanization on selection of multiple resistance in fecal coliform populations," Applied and Environmental Microbiology, Vol. 46, No. 1, 227-232, 1983.
14. Bernath Walker, S., Boutilier, T., and Hipel, K.W., "Systems Management Study of a Private Brownfield Renovation", Journal of Urban Planning and Development, published online on August 13, 2010, DOI: 10.1061/(ASCE)0733-9488(2010)136:3(249), Vol. 136, No. 3, pp. 249-260, 2010.
15. Blackstock, J.J., and Long, J.C.S., "The Politics of Geoengineering," Science, Vol. 327, January 29, 2010.
16. Bowman, C.W. and Albion, K.J., "Report on Canada's Energy Progress: 2007-2009," prepared for the Canadian Academy of Engineering, 2009.
17. Bowman, C.W. and Griesbach, R.C., "Energy Pathways Task Force, Phase 1 - Final Report". Canadian Academy of Engineering, Ottawa, Ontario, Canada, 2009. Available at www.acad-eng-gen.ca. Accessed on October 16, 2010.
18. Bowman, C.W., Marceau, R.J., and Griesbach, R.C., "Report of the Canada Power Grid Task Force", Canadian Academy of Engineering, Ottawa, Ontario, Canada, 2009. Available at www.acad-eng-gen.ca. Accessed on October 16, 2010.
19. Boyd, D.R., "Water: Water Consumption," Canada vs. The OECD: An Environmental Comparison, 2001. Available at http://www.environmentalindicators.com/htdocs/indicators/6wate.htm. Accessed on October 16, 2010.
20. Braun, D., "Boreal Forest Protection Critical to Survival as Climate Changes," National Geographic, November 12, 2009. Available at http://blogs.nationalgeographic.com/blogs/news/chiefeditor/2009/11/boreal-forest-

protection.html. Accessed on November 1, 2010.
21. Brown, L.R., "World on the Edge: How to Prevent Environmental and Economic Collapse," Earth Policy Institute, 2011.
22. Brubaker, E., "Weathering the Perfect Storm: Water Survival Strategies for Alberta's Municipalities," Presentation to Mayors and Chief Administrative Officers of Alberta municipalities at an EPCOR-sponsored function held in conjunction with the Alberta Urban Municipalities Association Conference, Environment Probe, November 4, 2009. Available at http://environment.probeinternational.org/publications/water-and-wastewater/weathering-perfect-storm-water-survival-strategies-albertas-munici. Accessed on October 22, 2010.
23. Bruce, J., "Oil and Water – Will They Mix in a Changing Climate? The Athabasca River Story," Government of Canada Policy Research Initiative, 2006. Available at http://policyresearch.gc.ca/doclib/Bruce_OIL-AND-WATER-Oct-23_FINAL.pdf. Accessed on April 15, 2011.
24. Bruce, J., Burton, I., Martin, H., Mills, B., and Mortsch, L., "Water Sector: Vulnerability and Adaptation to Climate Change," Final Report, 2000. Available at www.c-ciarn.mcgill.ca/watersector.pdf. Accessed on October 24, 2010.
25. Bruce, J. and Mitchell, B., "Broadening Perspectives on Water Issues," Canadian Global Change Program Incidental Report Series, No. IR95-1. Canadian Global Change Program and Canadian Water Resources Association, 1995. 38 pp., ISSN 1192-6481. Available at http://www.globalcentres.org/cgcp/english/html_documents/publications/water/toc.html. Accessed on April 9, 2011.
26. Burney, D., "Canada – US Electricity Trade: Challenges and Opportunities," mondaq, December 2, 2009. Available at http://www.mondaq.com/canada/article.asp?articleid=89950. Accessed on October 24, 2010.
27. Burton, P.J., Messier, C., Smith, D.W., Adamowicz, W.L. and Editors. "Towards Sustainable Management of the Boreal Forest," National Research Council of Canada Press, Ottawa, Ontario, 1036 pp., 2003.
28. Business Wire, "Strengthening Ontario's Leadership in Protecting Water," PR-inside.com, December 1, 2010. Available at http://www.pr-inside.com/strengthening-ontario-s-leadership-in-r2281845.htm. Accessed on December 2, 2010.
29. Byers, M., "The Devils' Diversion," The Globe and Mail. Toronto, Ontario, January 31, 2005.
30. Chen, Z. and Grasby, S.E., "Impact of Decadal and Century-Scale Oscillations on Hydroclimate Trend Analyses," Journal of Hydrology, Vol. 365, pp. 122–133, 2009.Canadian Association of Petroleum Producers (CAPP), "Backgrounder: Oil Sands Economic Impacts Across Canada," Calgary, Alberta, 2008a.
31. Canadian Association of Petroleum Producers (CAPP), "Crude Oil: Forecast, Market and Pipeline Expansions," Calgary, Alberta, 2009.
32. Canadian Association of Petroleum Producers (CAPP), "Environmental Challenges and Progress in Canada's Oil Sands," Calgary, Alberta, 2008b.

33. Canadian Association of Petroleum Producers (CAPP), "Oil Sands," 2011. Available at http://www.capp.ca/CANADAINDUSTRY/OILSANDS/Pages/default.aspx#K935U5sGnr9M. Accessed on May 5, 2011.
34. Canadian Council of Ministers of the Environment (CCME). Canada-wide Strategy for the Management of Municipal Wastewater Effluent. Ottawa, Ontario, 18 pp., 2009.
35. Canadian Council of Ministers of the Environment (CCME), "Glaciers," CCME Publications. Available at http://www.ccme.ca/assets/pdf/cc_ind_nature_glaciers_e.pdf. Accessed on August 26, 2010.
36. Canadian Encyclopedia, "James Bay Project," Historica-Dominion Institute, 2010. Available at http://www.thecanadianencyclopedia.com/index.cfm?PgNm=TCE&Params=A1ARTA0004099. Accessed on September 22, 2010.
37. Canadian Geographic, "Climate Prosperity Diagram," Degrees of Change, created by the Royal Canadian Geographical Society and National Roundtable on the Environment and the Economy, 2010a. Available at http://www.canadiangeographic.ca/climate-prosperity/degrees_of_change/CanGeoClimateChange_EN.html. Accessed on October 21, 2010.
38. Canadian Geographic, "James Bay," Just the Facts, 2010b. Available at http://www.canadiangeographic.ca/magazine/nd05/indepth/justthefacts.asp. Accessed on October 24, 2010.
39. Canadian Union of Public Employees, and Council of Canadians, "Public Water for Sale: How Canada will privatize our public water systems," A report to provincial, territorial and municipal governments regarding the Canada-European Union Comprehensive Economic and Trade Agreement, December 2010. Available at http://canadians.org/trade/documents/CETA/water-report-1210.pdf. Accessed on January 8, 2011.
40. Canadian Water Issues Council, "A Model Act for Preserving Canada's Waters," Munk Centre for International Studies, University of Toronto, February 2008. Available at http://www.powi.ca/pdfs/events/20080602-T49781-Briefing_EN.pdf. Accessed on February 5, 2011.
41. Carlson, M., Wells, J., and Roberts, D., "The Carbon the World Forgot," Boreal Songbird Initiative, 2009. Available at http://www.borealbirds.org/resources/carbon/report-full.pdf. Accessed on November 1, 2010.
42. CBC Ideas, "Speaking Truth to Power, Part 2," audio of proceedings of the Fresh Water Summit, held in Bracebridge, Ontario, Canada on June 1-2, 2010, aired June 24-25, 2010. Available at http://www.cbc.ca/ideas/episodes/2010/06/24/speaking-truth-to-power-part-1-2/. Accessed on October 24, 2010.
43. CBC Manitoba, "Manitoba Flood 2011," 2011. Available at http://www.cbc.ca/manitoba/features/flood2011/. Accessed on May 1, 2011.
44. CBC News, "Bottled Water: Quenching a planet's thirst," August 20, 2008. Available at http://www.cbc.ca/news/background/consumers/bottled-water.html. Accessed on October 2, 2010.
45. CBC News, "Devils Lake Reaction

Continues on Both Sides of Border", 2005. Available at http://www.cbc.ca/404.html?filename=mb_devilstues20050809. Accessed on August 9, 2005.

46. CBC News, "Prairies Losing Out on Water From Melting Glacier," January 10, 2003. Available at http://www.cbc.ca/health/story/2003/01/10/glacier030110.html. Accessed on October 21, 2010.
47. CBC News, "Sydney Tar Ponds Get $400-million Cleanup," May 13, 2004. Available at http://www.cbc.ca/news/story/2004/05/12/tarponds_20041012.html. Accessed on September 29, 2010.
48. CBC News, "Tar Ponds Timeline," January 29, 2007. Available at http://www.cbc.ca/news/background/tarponds/timeline.html. Accessed on September 29, 2010.
49. Centre for Energy, "Electricity Transmission in Canada," 2010. Available at http://www.centreforenergy.com/AboutEnergy/Electricity/Transmission/Overview.asp?page=6. Accessed on October 24, 2010.
50. Chapagain, A.K., Hoekstra, A.Y., and Savenije, H.H.G., "`Saving Water through Global Trade," UNESCO-IHE Institute for Water Education, 2005. Available at http://doc.utwente.nl/58373/1/Report17.pdf. Accessed on October 2, 2010.
51. Christensen, R. and Lintner, A.M., "Trading Our Common Heritage? The Debate over Water Rights Transfers in Canada," in Bakker, K. (Editor), "Eau Canada: The Future of Canada's Water", University of British Columbia Press, Vancouver, British Columbia, Canada, 2007.
52. Conservation Ontario, "The Clean Water Act," 2009. Available at http://conservation-ontario.on.ca/source_protection/Clean_Water_Actindex.htm. Accessed on January 7, 2011.
53. Council of Canadians, "Five reasons to ban bottled water," October 28, 2008. Available at http://www.canadians.org/water/issues/Unbottle_It/factsheet.html. Accessed on September 29, 2010.
54. Council of Canadian Academies (CCA), "The Sustainable Management of Groundwater in Canada," Ottawa, 337 pp., 2009.
55. Crawford, T., "Western Leaders Draw Water Charter to Protect this Resource," Vancouver Sun, June 16, 2010. Available at http://www.vancouversun.com/business/Western%20leaders%20draw%20water%20charter%20protect%20resource/3159224/story.html#ixzz0rGNpo8u0. Accessed on October 24, 2010.
56. Cross, A., "Researchers alarmed at bacteria in Canadian bottled water," Canwest News Service, in The Vancouver Sun, May 28, 2010. Available at http://www.vancouversun.com/health/Researchers+alarmed+bacteria+Canadian+bottled+water/3072771/story.html. Accessed on September 27, 2010.
57. CTV News, "Some tap water safer than bottled water: report," October 6, 2006. Available at http://www.ctv.ca/CTVNews/TopStories/20061005/bottled_water_061005/. Accessed on September 27, 2010.
58. de Loë, R.C., "A Canadian Vision and Strategy for Water in the 21st Century," Policy Options, Vol. 30, No. 7, July-August 2009.
59. de Loë, R.C., "Toward a Canadian National Water Strategy," Final Report,

Prepared for the Canadian Water Resources Association, Rob de Loë Consulting Services, Guelph, Ontario, 2008. Available at http://www.cwra.org/resource/assets/CNWS_Report_Final_2008_06_18.pdf. Accessed on November 8, 2010.

60. de Loë, R.C., "Transboundary Water Governance in the Mackenzie River Basin, Canada," Prepared for the 7th Biennial Rosenberg International Forum on Water Policy, Buenos Aires, Republic of Argentina, November 15-17, 2010.
61. De Sousa, C., "Contaminated sites: The Canadian situation in an international context", Journal of Environmental Management, 62, 131–154, 2001.
62. De Villiers, M., "Water," second edition, McClelland And Stewart, Toronto, 453 pp., 2003.
63. Dellapenna, J.W., "The Case Against Markets," In U. Shamir (Editor), Negotiation Over Water, Proceedings of the Haifa Workshop, 1997, IHP–V, Technical Documents in Hydrology. United Nations Educational, Scientific and Cultural Organization (UNESCO), Paris, 53, pp. 34-48, 2001.
64. Division of Ocean Affairs, Law of the Sea: Official text of the United Nations Convention on the Law of the Sea of 10 December 1982 and of the agreement relating to the implementation of Part XI. United Nations Press, New York, 1997.
65. Dowdeswell, L., Dillon, P., Ghoshal, S., Miall, A., Rasmussen, J., and Smol, J.P., "A Foundation for the Future: Building an Environmental Monitoring System for the Oil Sands," A report submitted to the Minister of Environment, Environment Canada, December 2010. Available at http://ec.gc.ca/pollution/default.asp?lang=En&n=E9ABC93B-1. Accessed on December 27, 2010.
66. Dyer, G., "Climate Wars," Random House Canada, 2008.
67. Eagleson, P.S., "Dynamic Hydrology," McGraw-Hill, New York, 1970.
68. Edmonton Journal, "Harper to Limit Bitumen Exports," September 27, 2008. Available at http://www.canada.com/edmontonjournal/news/story.html?id=89c1f48e-853f-403a-a117-6b33b111f360. Accessed on July 15, 2010.
69. Eggertson, L., "Investigative report: 1766 boil-water advisories now in place across Canada," Canadian Medical Association, 2008. Available at http://www.cmaj.ca/cgi/content/full/178/10/1261. Accessed on January 23, 2011.
70. Energy Resources Conservation Board (ERCB), "Alberta's Energy Reserves 2008 and Supply/Demand Outlook 2009-2018," Calgary, Alberta, June 2009. Available at http://www.ercb.ca/docs/products/STs/st98-2009.pdf. Accessed on November 2, 2010.
71. Environment Canada, "Hydrometric Data," 2010. Available at http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm. Accessed on May 4, 2011.
72. Environment Canada, "Shared Waters: Canada - United States," 2011. Available at http://www.ec.gc.ca/eau-water/default.asp?lang=en&n=B947BAA8-1#Canada. Accessed on February 15, 2011.
73. Environment Canada, "Threats to water availability in Canada," National Water Research Institute, Burlington, Ontario, Canada, NWRI Scientific Assessment

Report Series, No. 3, and ACSE Science Assessment Series, No. 1, p. 128, 2004.
74. Environment Canada, "Water – The Great Lakes," 2009. Available at http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=678C2760-1#a5. Accessed on April 15, 2011.
75. Environment News Service, "Scientists Urge Conservation of Canada's Precious Northern Forest," May 16, 2007. Available at http://www.ens-newswire.com/ens/may2007/2007-05-16-03.html. Accessed on November 1, 2010.
76. Eyles, N. and Miall, A., "Canada Rocks: The Geological Journey," Fitzhenry and Whiteside, Markham, Ontario, 2007.
77. Fang, L., Hipel, K.W., and Kilgour, D.M., "Interactive Decision Making: The Graph Model for Conflict Resolution", Wiley, New York, 221 pp., 1993.
78. Finch, G. R. and Smith, D. W., "The survival of antibiotic-resistant escherichia coli in an activated sludge plant," Environmental Technology Letters, Vol. 7, pp. 487-494, 1986.
79. Fisheries and Oceans Canada, "Fluctuations in Lake Levels – Types," The Canadian Hydrographic Service Central and Arctic Region, 2007. Available at http://www.lau.chs-shc.gc.ca/C&A/fluctuations_e.html#TC11. Accessed on April 15, 2011.
80. Gallangher, P. and Wood, L. (Editors), "Water and the Future of Life on Earth," Proceedings from the workshop and think tank held May 22-24, 2002, published by Simon Fraser University, Burnaby, British Columbia, Canada, 2003.
81. Gardiner, S.M., "A Perfect Moral Storm: The Ethical Tragedy of Climate Change," Oxford University Press, New York, 2011.
82. Garrison Diversion Unit Commission, "Final Report," Secretary of the Interior, Washington, D.C., December 20, 1984.
83. Gleick, P.H., "Water and Conflict: Fresh Water Resources and International Security," International Security, Vol. 18, No. 1, pp. 79-112, 1993.
84. Global Water Partnership (GWP) and International Network of Basin Organization (INBO), "A Handbook for Integrated Water Resources Management in Basins," published by GWP and INBO, 2009. Available at www.gwpforum.org and www.inbo-news.org. Accessed on October 15, 2010.
85. Gordon Water Group, "Changing the Flow: A Blueprint for Federal Action on Freshwater," 2008. Available at http://www.flowcanada.org/sites/default/files/ChangingtheFlow.pdf. Accessed on January 22, 2011.
86. Government of Alberta, "Responsible Actions: A Plan for Alberta's Oil Sands," Treasury Board, 2009. Available at http://treasuryboard.alberta.ca/docs/GOA_ResponsibleActions_web.pdf. Accessed on May 11, 2011.
87. Government of Canada, "Canada-U.S. Energy Relations," 2009. Available at http://www.canadainternational.gc.ca/washington/bilat_can/energy-energie.aspx?lang=eng. Accessed on October 17, 2010.
88. Government of Quebec, "Quebec Water Policy," 2002. Available at http://www.mddep.gouv.qc.ca/eau/politique/index-en.htm. Accessed on October 16, 2010.
89. Grand River Conservation Authority (GRCA), "REPORT NO. GM-05-10-25,"

May 28, 2010. Available at http://www.grandriver.ca/governance/GM051025.pdf. Accessed on May 4, 2011.

90. Grand River Conservation Authority (GRCA), "The Grand River Watershed," 2011. Available at http://www.grandriver.ca/index/document.cfm?Sec=12&Sub1=55&Sub2 =24. Accessed on August 3, 2011.
91. Grant, J., Dyer, S., and Woynillowicz, D. "Fact or Fiction: Oil Sands Reclamation," Pembina Institute, Drayton Valley, Alberta, 2008.
92. Grasby, S.E., "Impact on Water Resources, Drought in the West?," Gussow/Nuna Conference: The Geoscience of Climate and Energy, Canadian Society of Petroleum Geologists and Geological Association of Canada, Banff, Alberta, October 2008. Available at http://www.cspg.org/conventions/abstracts/2008Gussow/013.pdf. Accessed on October 18, 2010.
93. Grasby, S.E., Chen, Z., Hamblin, A.P., Wozniak, P.R.J., and Sweet, A.R., "Regional Characterization of the Paskapoo Bedrock Aquifer System, Southern Alberta," Canadian Journal of Earth Sciences, Vol. 45, No. 12, pp. 1501-1516, 2008.
94. Great Lakes – St. Lawrence River Sustainable Water Resources Agreement, December 13, 2005. Available at http://www.cglg.org/projects/water/docs/12-13-05/Great_Lakes-St_Lawrence_River_Basin_Sustainable_Water_Resources_Agreement.pdf. Accessed on October 18, 2010.
95. Grescoe, T., "After the deluge: Water powered the Saguenay region's economy, then almost destroyed it", Canadian Geographic and L'Actualité, 1997. Available at http://www.canadiangeographic.ca/magazine/ma97/feature_saguenay_floods.asp. Accessed on October 17, 2010.
96. Gunderson, L.H. and Holling, C.S. (Editors), "Understanding Transformations in Human and Natural Systems," Island Press, Washington, 2002.
97. Gunderson, L.H. and Light, S.S., "Adaptive Management and Adaptive Governance in the Everglades," Policy Sciences, Vol. 39, No. 4, pp. 323-334, 2006.
98. Hansen, J., "Storms of my Grandchildren," Bloomsbury, New York, 2009.
99. Health Canada, "Frequently Asked Questions about Bottled Water," Food and Nutrition, 2009. Available at http://www.hc-sc.gc.ca/fn-an/securit/facts-faits/faqs_bottle_water-eau_embouteillee-eng.php#a2. Accessed on September 27, 2010.
100. Heathcote, I.W., "Critical Challenges in Integrated Water Management," Journal of Policy Engagement, Vol. 2, No. 6, December 2010.
101. Hipel, K.W. and Bowman, C.W., "Is our energy superpower vision slipping away?", Toronto Star (thestar.com), March 16, 2011. Available at http://www.thestar.com/opinion/editorialopinion/article/955245--is-our-energy-superpower-vision-slipping-away. Accessed on May 13, 2011.
102. Hipel, K.W. and Fang, L., "Multiple Participant Decision Making in Societal and Technological Systems", in Arai, T., Yamamoto, S. and Makino, K. (Editors), Systems and Human Science – For

Safety, Security, and Dependability: Selected Papers of the 1st International Symposium, SSR2003, Osaka, Japan, published by Elsevier, Amsterdam, The Netherlands, Chapter 1, pp. 3-31, 2005.

103. Hipel, K.W., Fang, L., and Kilgour, D.M., “Decision Support Systems in Water Resources and Environmental Management”, Journal of Hydrologic Engineering, Vol. 13, No. 9, pp. 761-770, 2008a.
104. Hipel, K.W. and Fraser, N.M., “Metagame Analysis of the Garrison Conflict,” Water Resources Research, Vol. 17, No. 4, pp. 627-637, 1980.
105. Hipel, K.W., Hegazy, T., and Yousefi, S., “Combined Strategic and Tactical Negotiation Methodology for Resolving Complex Brownfield Conflicts”, Pesquisa Operacional, special issue on Soft OR and Complex Societal Problems, Vol. 30, No. 2, pp. 281-304, 2010.
106. Hipel, K.W., Kilgour, D.M., and Zhao, N.Z., “Risk Analysis of the Walkerton Drinking Water Crisis”, Canadian Water Resources Journal, Vol. 28, No. 3, pp. 395-419, 2003.
107. Hipel, K.W. and McLeod, A.I., “Time Series Modelling of Water Resources and Environmental Systems,” Elsevier, Amsterdam, 1994.
108. Hipel, K.W. and Obeidi, A., “Trade versus the Environment: Strategic Settlement from a Systems Engineering Perspective”, Systems Engineering, Vol. 8, No. 3, pp. 211-233, 2005.
109. Hipel, K.W., Obeidi, A., Fang, L., and Kilgour, D.M., “Adaptive Systems Thinking in Integrated Water Resources management with Insights into Conflicts over Water Exports,” INFOR, Vol. 46, No. 1, pp. 51-69, 2008b.
110. Hipel, K.W., Obeidi, A., Fang, L., and Kilgour, D.M., “Sustainable Environmental Management from a System of Systems Perspective”, In System of Systems Engineering: Innovations for the 21st Century, edited by M. Jamshidi, Wiley, New York, Chapter 18, pp. 443-481, 2009.
111. Holling, C.S. (Editor), “Adaptive Environmental Assessment and Management,” Chichester: Wiley, 1978.
112. Homer-Dixon, T.F., “Plan Z: Global Responses to a Climate Emergency,” speech given at workshop held at the Briarhurst Institute in Fergus, Ontario, under the sponsorship of the Centre for International Governance Innovation, on September 17th and 18th, 2009.
113. Homer-Dixon, T.F., “The Upside of Down: Catastrophe, Creativity and the Renewal of Civilization,” Washington, Island Press, 2006.
114. Horbulyk, T.M., “Liquid Gold? Water Markets in Canada,” in Bakker, K. (Editor), “Eau Canada: The Future of Canada’s Water”, University of British Columbia Press, Vancouver, British Columbia, Canada, 2007.
115. Hrudey, S.E., Gosselin, P., Naeth, M.A., Plourde, A., Therrien, R., Van Der Kraak, G., and Xu, Z., “Environmental and Health Impacts of Canada’s Oil Sands Industry,” Royal Society of Canada Expert Panel Report, 2010, 414 pp. Available at http://www.rsc.ca/documents/expert/RSC%20report%20complete%20secured%209Mb.pdf. Accessed on December 17, 2010.

116. Humphries, M., "North American Oil Sands: History of Development, Prospects for the Future," Congressional Research Service, Washington, DC, 2008.
117. Hydro-Québec, "Hydro-Québec's Electricity Facts: Energy Supplies and Air Emissions," 2009. Available at http://www.hydroquebec.com/sustainable-development/documentation/pdf/etiquette_achats_en.pdf. Accessed on October 24, 2010.
118. Hydro-Québec, "James Bay Project," 2010. Available at http://www.hydroquebec.com/sustainable-development/documentation/pdf/autres/pop_06_02.pdf. Accessed on October 15, 2010.
119. Interamerican Academies of Science (IANAS), "Managua Declaration," jointly written at the Fourth Meeting of the Focal Points of the IANAS Water Programme which was held at the Auditorio Carlos Martinez Rivas, Universidad National Autonoma de Nicaragua (UNAN) in Managua, on May 30th and 31st, 2009.
120. International Energy Agency, "Electricity," 2008. Available at http://www.eia.doe.gov/cabs/Canada/Electricity.html. Accessed on October 15, 2010.
121. International Joint Commission (IJC), "Impacts on Upper Great Lakes Water Levels: St. Clair River," Final Report to the International Joint Commission, December 2009a. Available at http://pub.iugls.org/en/Other_Publications/IUGLS_Final_Report.pdf. Accessed on October 19, 2010.
122. International Joint Commission (IJC), "Protection of the Waters of the Great Lakes", Final Report to the Governments of Canada and the United States, February 27, 2000. Available at http://www.ijc.org/php/publications/html/finalreport.html. Accessed on October 15, 2010.
123. International Joint Commission (IJC), "Rules of Procedure and Text of Treaty," Ottawa, Canada – Washington, D.C., 1965.
124. International Joint Commission (IJC), "The International Watersheds Initiative: Implementing a New Paradigm for Transboundary Basins," Ottawa, Canada – Washington, D.C., 2009b. Available at http://www.ijc.org/php/publications/pdf/ID1627.pdf. Accessed on October 15, 2010.
125. International Joint Commission (IJC), "Transboundary Implications of the Garrison Diversion Unit," Report to the Governments of Canada and the United States, Ottawa, Canada – Washington, D.C., 1977.
126. International Upper Great Lakes Study, "Ìmpacts on Upper Great Lakes Water Levels: St. Claire River," Final Report to the International Joint Commission, December 2009. Available at http://pub.iugls.org/en/Other_Publications/IUGLS_Final_Report.pdf. Accessed on April 17, 2011.
127. Jain, S.K. and Singh, V.P., "Water Resources Systems Planning and Management", Elsevier, New York, 2003.
128. Johnson, B., "Potential Impact of Selected Agricultural Chemical Contaminants on a Northern Prairie Wetland: A Microcosm Evaluation," Environmental Toxicology and Chemistry,

Vol. 5, No. 5, pp. 473-485, 1986. Abstract available at http://onlinelibrary.wiley.com/doi/10.1002/etc.5620050507/abstract. Accessed on October 29, 2010.

129. Kart, J., "Adaptive Management Means Managing to Learn," International Upper Great Lakes Study, 2010. Available at http://www.iugls.org/adaptive-management-story.aspx. Accessed on January 20, 2011.

130. Kelly, E., Schindler, D., Hodson, P., Short, J., Radmanovich, R., and Nielsen, C., "Oil Sands Development Contributes Elements Toxic at Low Concentrations to the Athabasca River and Its Tributaries," Proceedings of the National Academy of Sciences of the United States of America, 2010. Available at http://www.pnas.org/content/107/37/16178. Accessed on October 1, 2010.

131. Kelly, E., Short, J., Schindler, D., Hodson, P., Ma, M., Kwan, A., and Fortin, B., "Oil Sands Development Contributes Polycyclic Aromatic Compounds to the Athabasca River and Its Tributaries," Proceedings of the National Academy of Sciences of the United States of America, 2009. Available at http://www.pnas.org/content/106/52/22346. Accessed on October 1, 2010.

132. Kerr, J.L., Guo, Z., Smith, D.W., Goss, G.G. and Belosevic, M., "Use of goldfish (Carassius auratus L.) for assessment of xenobiotic presence in wastewater and reuse water," Journal of Environmental Engineering and Science, Vol. 7, No. 4, 2008.

133. Kim, Y.-J., Hipel, K.W., and Bowman, C.W., "Water Problems in Canada´s Oil Sands," unpublished manuscript, Department of Systems Design Engineering, University of Waterloo, Waterloo, Ontario, Canada, 2011.

134. Lapp, S., Byrne, J., Townshend, I., and Kienzle, S., "Climate Warming Impacts on Snowpack Accumulation in an Alpine Watershed," International Journal of Climatology, Vol. 25, pp. 521-536, 2005.

135. Lem, S., "Canada: Too Many Plastic Bottles, Too Little Landfill," The Toronto Sun, in Inside the Bottle, May 26, 2008. Available at http://www.insidethebottle.org/canada-too-many-plastic-bottles-too-little-landfill. Accessed on October 4, 2010.

136. Lenton, R. and Muller, M. (Editors), "Integrated Water Resources Management in Practice: Better Water Management for Development," Earthscan, London, United Kingdom, 2009.

137. Leung, L.R. and Ghan, S.J., "Pacific Northwest Climate Sensitivity Simulated by a Regional Climate Model Driven by a GCM. Part II: 2×CO2 Simulations," Journal of Climate, Vol. 12, pp. 2031-2053, 1999.

138. Levels Reference Study Board, "Levels Reference Study, Great Lakes-St. Lawrence River Basin," submitted to the International Joint Commission, 1993.

139. Loucks, D.P., "Water Resources Systems Planning and Management: An Introduction to Methods, Models, and Applications," Division of Water Sciences, United Nations Educational, Scientific and Cultural Organization (UNESCO), Paris, 2004.

140. Lupick, T., "B.C. Glaciers Steadily Disappearing," straight.com, Vancouver,

British Columbia, Canada, October 2, 2008. Available at http://www.straight.com/article-164354/bc-glaciers-steadily-disappearing. Accessed on October 21, 2010.

141. Ma, J., Hipel, K.W., and De, M., "Devils Lake Emergency Outlet Diversion Conflict", Journal of Environmental Management, Vol. 92, No. 2, pp. 437-447, 2011.
142. Ma, J., Hipel, K.W., De, M., and Cai, J., "Transboundary Water Policies: Assessment, Comparison and Enhancement", Water Resources Management, Vol. 22, pp. 1069-1087, 2008.
143. Ma, K., "Chapter 3: Searching the Waters – The Water Crisis," End to End – The State of the Sturgeon River and the Alberta Water Crisis, Master's Research Project, Carleton University, May 16, 2006. Available at http://www.bless.ab.ca/Documents/EndToEnd/MaMRPChap3v3.pdf. Accessed on August 25, 2010.
144. Maas, A., Hufschmidt, M.M., Dorfman, R., Thomas Jr., H.A., Marglin, S.A., and Fair, M.G., "Design of Water-Resource Systems", Harvard University Press, Cambridge, Massachusetts, 1962.
145. Manitoba Water Stewardship, "Regional map - drainage basins and Garrison features," Potential Transboundary Water Projects. Available at http://www.gov.mb.ca/waterstewardship/water_info/transboundary/potential.html. Accessed on October 15, 2010.
146. Marsden, W., "Stupid to the Last Drop: How Alberta is Bringing Environmental Armageddon to Canada (and Doesn't Seem to Care)", Vintage Canada, Toronto, Ontario, 2008.
147. McCarthy, S., "Heat is on Arctic as Temperatures on Rise, Sea Ice Melts," The Globe and Mail, December 3, 2010.
148. McKenzie-Brown, P., "New Computer Modeling System Allows Exploration of Canada's Potential Energy Future," Oilsands Review. August 2008, pp. 24–26, 2009.
149. McMurty, J., "Value Wars," Pluto Press, London, United Kingdom, 2002.
150. Miall, A., "Forget gimmicks – think energy," The Globe and Mail, April 22, 2011.
151. Miltenberger, J.M., "Northern Voices, Northern Waters: Traditional Knowledge and Water Policy Development in the Northwest Territories," A Discussion Paper prepared for the Rosenberg International Forum on Water Policy, 2010.
152. Montreal Gazette, "Churchill Falls deal probed," CanWest MediaWorks Publications Inc., December 20, 2005, in Canada.com. Available at http://www.canada.com/montrealgazette/story.html?id=17f52755-7ede-45a5-8b2f-6a8b7d004957. Accessed on September 25, 2010.
153. Mourougane, A., "Achieving Sustainability of the Energy Sector in Canada," Economic Department Working Paper No. 618, Organization for Economic Co-operation and Development, Paris, France, June 2008.
154. Nalcor Energy, "Churchill Falls," 2010a. Available at http://www.nalcorenergy.com/churchill-falls.asp. Accessed on October 24, 2010.
155. Nalcor Energy, "`Requests for Proposals

Issued for the Lower Churchill Falls Project," July 9, 2010b. Available at http://www.nalcorenergy.com/assets/final%20lcp%20rfp%20news%20release%20-%20july%209%202010.pdf. Accessed on October 24, 2010.

156. National Energy Board (NEB), "Canada's Oil Sands: Opportunities and Challenges to 2015," An Energy Market Assessment, Calgary, Alberta, 2004.

157. National Research Council, "Adapting to the Impacts of Climate Change," National Academy of Sciences, Panel on Adapting to the Impacts of Climate Change, 2010a.

158. National Research Council, "Adaptive Management for Water Resources Project Planning," National Academies Press, Washington, D.C., 2004.

159. National Research Council, "Advancing the Science of Climate Change," National Academy of Sciences, Panel on Advancing the Science of Climate Change, 2010b.

160. National Research Council, "Informing an Effective Response to Climate Change," National Academy of Sciences, Panel on Informing an Effective Response to Climate Change, 2010c.

161. National Research Council, "Limiting the Magnitude of Climate Change," National Academy of Sciences, Panel on Limiting the Magnitude of Climate Change, 2010d.

162. Natural Resources Canada (NRCan), "Forest regions classification," Classification, 2007, Available at http://ecosys.cfl.scf.rncan.gc.ca/classification/intro-region-eng.asp. Accessed on August 9, 2011.

163. Natural Resources Canada (NRCan), "Freshwater: The Role and Contribution of Natural Resources Canada," Sustainable Development, 2010. Available at http://www.nrcan-rncan.gc.ca/sd-dd/pubs/h2o/issque-1-eng.php?PHPSESSID =95df6485cd782f2c0f188dea209072ca#ess1c. Accessed on October 26, 2010.

164. Natural Resources Canada (NRCan), "Glaciers and Icefields," The Atlas of Canada, 2009. Available at http://atlas.nrcan.gc.ca/auth/english/maps/freshwater/distribution /glaciers/1. Accessed on October 25, 2010.

165. Natural Resources Canada (NRCan), "Great Lakes Basin," Provincial and Territorial , 2003. Available at http://atlas.nrcan.gc.ca/auth/english/maps/reference /provincesterritories/gr_lks/referencemap_image_view. Accessed on April 16, 2004.

166. Natural Resources Canada (NRCan), "Impacts on Water Supply," Climate Change Impacts and Adaptation: A Canadian Perspective, 2007. Available at http://adaptation.nrcan.gc.ca/perspective/water_3_e.php. Accessed on October 25, 2010.

167. Natural Resources Canada (NRCan), "Map of Canada," 2002, in Water Resources in Canada: A Strategic View, Hipel, K., Miall, A., Smith, D., Inter American National Academies of Science (IANAS) Meeting, Managua, Nicaragua, May 30-31, 2009.

168. Natural Resources Canada (NRCan), "Map of Prairie Provinces", 2003. Available at http://atlas.nrcan.gc.ca/auth/english/maps/reference/

provincesterritories/prairie_provinces/referencemap_image_view. Accessed on October 15, 2010.

169. Natural Resources Canada (NRCan), "Map of the Red River and the central portion of the Red River Valley, Manitoba, depicting the limits of the 1997 flood and places and features mentioned in the text," Geoscientific Insights into the Red River and Its Flood Problem in Manitoba Geological Controls on Red River Flooding, 2008. Available at http://gsc.nrcan.gc.ca/floods/redriver/geological_e.php. Accessed on August 22, 2010.
170. Natural Resources Canada (NRCan), "Melting Glaciers", The Winds of Change: Climate Change in Prairie Provinces, 2001. Available at http://adaptation.nrcan.gc.ca/posters/pr/pr_04_e.php. Accessed on October 21, 2010.
171. National Round Table on the Environment and the Economy (NRTEE), "Cleaning up the Past, Building the Future: A National Brownfield Redevelopment Strategy for Canada", ISBN 1-894737-05-9, Ottawa, Canada, 2003.
172. Neumann, N. F., Smith, D. W. and Belosevic, M., "Waterborne disease: An old foe re-emerging?", Journal of Environmental Engineering and Science, Vol. 4, No. 3, p. 155, 2005.
173. Ng, G. and Felder, M., "Water and the Future of the Canadian Economy," The Innovolve Group, 2010. Available at http://bluewater.rbc.com/news/CDN_Water_Report_PDF_English.pdf. Accessed on February 2, 2011.
174. Nikiforuk, A., "On the Table: Water, Energy and North American Integration," prepared on behalf of the Program on Water Issues, Munk Centre for International Studies, University of Toronto, October 16, 2007. Available at http://www.powi.ca/pdfs/waterdiversion/waterdiversion_onthetable_new.pdf. Accessed on February 7, 2011.
175. Nikiforuk, A., "Tar Sands: Dirty Oil and the Future of a Continent," Greystone Books, Vancouver, British Columbia, 2008.
176. Noble, B.F., "Applying Adaptive Environmental Management," pp. 442–466 in B. Mitchell, (Editor), Resource and Environmental Management in Canada, Oxford University Press, Don Mills, Ontario, Canada, 2004.
177. Noone, M.S., "The Dilemma of Devils Lake Part 1." The Western Planner, Casper, Wyoming, Vol. 25, No. 4, 2004.
178. Noone, M.S., "The Dilemma of Devils Lake Part 2." The Western Planner, Casper, Wyoming, Vol. 26, No. 2, 2005.
179. North Dakota State Government, "Devils Lake (Peterson Coulee) Outlet Request for Proposal", 2001. Available at http://www.gov.mb.ca/waterstewardship/transboundary/devilslake/rfp.html. Accessed on March 8, 2005.
180. North Dakota State Water Commission, "Devils Lake Flood Facts", 2010. Available at http://www.swc.state.nd.us/4DLink9/4dcgi/GetContentPDF/PB-206/DL_Quick_Facts.pdf. Accessed on July 20, 2010.
181. Obeidi, A., and Hipel, K.W., "Strategic and Dilemma Analyses of a Water Export Conflict", INFOR, Vol. 43, No. 3, pp. 247-270, 2005.

182. Obeidi, A., Hipel, K.W., and Kilgour, D.M., "Canadian Bulk Water Exports: Analyzing the Sun Belt Conflict using the Graph Model for Conflict Resolution", Knowledge, Technology, and Policy, Vol. 14, No. 4, pp. 145-163, 2002.
183. Ontario Ministry of the Environment, "Survey of the Occurrence of Pharmaceuticals and Other Emerging Contaminants in Untreated Source and Finished Drinking Water in Ontario Ministry of the Environment," PIBS 7269e, 2006. Available at
184. PIBS 7269e http://www.ene.gov.on.ca/publications/7269e.pdf. Accessed on October 29, 2010.
185. Owen, B., and Rabson, M., "Devils Lake health threat rising daily", Winnipeg Free Press, 2010. Available at http://www.winnipegfreepress.com/local/devils-lake-health-threat-rising-daily-97370884.html. Accessed on July 20, 2010.
186. Pacific Institute, "Bottled Water and Energy: A Fact Sheet," 2006. Available at http://www.pacinst.org/topics/water_and_sustainability/bottled_water/bottled_water_and_energy.html. Accessed on September 20, 2010.
187. Parks Canada, "Reservoirs of the Rockies," Time for Nature, August 18, 2003. Available at http://www.pc.gc.ca/canada/pn-tfn/itm2-/2003/au/index_e.asp. Accessed on October 21, 2010.
188. Parrott, J. and Blunt, B., "Life-cycle exposure of fathead minnows (Pimephales promelas) to an ethinylestradiol concentration below 1 ng/L reduces egg fertilization success and demasculinizes males," Environmental Toxicology, Vol. 20, No. 2, pp. 131-141, 2005. Abstract available at http://onlinelibrary.wiley.com/doi/10.1002/tox.20087/abstract?systemMessage=Due+to+scheduled+maintenance+access+to+the+Wiley+Online+Library+may+be+disrupted+as+follows%3A+Saturday%2C+30+October+-+New+York+0500+EDT+to+0700+EDT%3B+London+1000+BST+to+1200+BST%3B+Singapore+1700+SGT+to+1900+SGT. Accessed on October 29, 2010.
189. Parsons, L., "Ontario Inquiry Finds Tory Government Responsible for Walkerton Deaths," World Socialist Web Site, August 3, 2002. Available at http://www.wsws.org/articles/2002/aug2002/walk-a03.shtml. Accessed on October 28, 2010.
190. Pearse, P.H., "Water Management in Canada: The Continuing Search for the Federal Role," Keynote Address at the 51st Annual Conference of the Canadian Water Resources Association, Victoria, BC, pp. 10-12, 1998.
191. Petroleum Technology Alliance Canada (PTAC), "Water Use in Alberta Oil Sands," May 29, 2007. Available at http://www.albertacanada.com/documents/AIS-ENVIRO_oilsands07.pdf. Accessed on September 2, 2010.
192. Petroleum World, cited in National Energy Board, "Canada's Oil Sands: Opportunities and Challenges to 2015," An Energy Market Assessment, May 2004, p. 109.
193. Polaris Institute, "University of Winnipeg Bans Bottled Water!", March 23, 2009. Available at http://www.polarisinstitute.org/university_of_winnipeg_bans_bottled_water. Accessed on September 26, 2010.

194. Pollution Probe, "Towards a Vision and Strategy for Water Management in Canada," 2008. Available at http://www.pollutionprobe.org/Reports/WPWS%20Final%20Report%202007.pdf. Accessed on January 22, 2011.
195. Prebble, P., Coxworth, A., Simieritsch, T., Dyer, S. Huot, M., and Walsh, H., "Carbon Copy: Preventing Oil Sands Fever in Saskatchewan," Oil Sands Fever Series, Pembina Institute, Saskatchewan Environmental Society, Canadian Parks and Wilderness Society, Drayton Valley, Alberta, 2009.
196. Prime Minister Stephen Harper, St. Petersburg, Russia, 2006 G8 Summit.
197. Pugwash, "Freshwater Declaration," Canadian Pugwash and Science for Peace, Freshwater Expert Roundtable, Global Issues Project, November 8-9, 2008. Available at http://www.rwsandford.ca/2009.01.15-freshwater_declaration-EN.pdf. Accessed on May 1, 2011.
198. Rajabi, S., Hipel, K.W., and Kilgour, D.M., "Multiple Criteria Screening of a Large Water Policy Subset Selection Problem," Journal of the American Water Resources Association, Vol. 3, No. 3, pp. 533-546, June 2001.
199. Reisner, M., "Cadillac Desert," Penguin Books, New York, 582 pp., 1993.
200. Reuters, "UPDATE 2-Pipe break hits U.S., Canada refineries," July 26, 2010. Available at http://www.reuters.com/article/2010/07/27/enbridge-idUSN2623027120100727. Accessed on May 14, 2011.
201. Richardson, G.R.A., "Adapting to Climate Change: An Introduction for Canadian Municipalities," National Resources Canada, Ottawa, ON, 2010. Available at http://adaptation.nrcan.gc.ca/mun/pdf/mun_e.pdf. Accessed on April 9, 2011.
202. Richardson, L., "The Oil Sands: Toward Sustainable Development," Report of the Standing Committee on Natural Resources, 39th Parliament, 1st session, House of Commons, Ottawa, Ontario, 2007.
203. Rinehart, D., "Watergate, How bottled water could drink Canada dry," The Hamilton Spectator, March 3, 2007, in Polaris Institute. Available at http://www.polarisinstitute.org/watergate_how_bottled_water_could_drink_canada_dry_0. Accessed on September 28, 2010.
204. Rutter, N., Coppold, M., and Rokosh, D., "Climate change and landscape in the Canadian Rocky Mountains", The Burgess Shale Geoscience Foundation, Field, British Columbia, 2006.
205. Saleth, M.R., "Institutional Response as an Adaptation to Water Scarcity," Madras Institute of Development Studies, 2010.
206. Salmon, S.M.A., "The Helsinki Rules, the UN Watercourses Convention and the Berlin Rules: Perspectives on International Water Law," Water Resources Development, Vol. 23, No. 4, pp. 625-640, December 2007. Available at http://www.internationalwaterlaw.org/bibliography/articles/general/Salman-BerlinRules.pdf. Accessed on December 8, 2010.
207. Sandford, R., "Water, Weather and the Mountain West", Rocky Mountain Books, Canada, pp. 88-90, 2007.
208. Sandford, R., "Restoring the Flow:

Confronting the World's Water Woes", Rocky Mountain Books, Canada, 2009.

209. Schindler, D.W., "Forward," in Bakker, K. (Editor), "Eau Canada: The Future of Canada's Water", University of British Columbia Press, Vancouver, British Columbia, Canada, 2007.
210. Schindler, D.W. and Adamowicz, V., "Running out of Steam? Oil Sands Development and Water Use in the Athabasca River-Watershed: Science and Market Based Solutions," University of Alberta, Edmonton, Alberta, 2007.
211. Schindler, D.W. and Donahue, W.F., "An Impending Water Crisis in Canada's Western Prairies Provinces," Proceedings of the National Academy of Sciences, Vol. 103, No. 19, pp. 7210-7216, 2006.
212. Schwartz, D., "Profile: David Schindler," CBC News, October 18, 2010. Available at http://www.cbc.ca/canada/story/2010/10/15/f-david-schindler.html. Accessed on November 1, 2010.
213. Science and Environmental Health Network (SEHN), "Precautionary Principle," January 26, 1998. Available at http://www.sehn.org/wing.html. Accessed on May 7, 2005.
214. Sea Grant Michigan, "Great Lakes Basin Map," About the Great Lakes, 2009. Available at http://www.miseagrant.umich.edu/explore/greatlakes/index.html. Accessed on September 8, 2010.
215. Sego, D. "Environmental Impact of the Oil Sands Development," Geoscience of Climate Change, 2008 Gussow-Nuna Geoscience Conference, Banff, Alberta, 2008.
216. Servos, M. R., Bennie, D. T., Burnison, B. K., Jurkovic, A., McInnis, R., Neheli, T., Schnell, A., Seto, P., Smyth, S. A. and Ternes, T. A., "Distribution of estrogens, 17β-estradiol and estrone, in Canadian municipal wastewater treatment plants," Science of the Total Environment, Vol. 336, No. 1-3, pp. 155-170, 2005.
217. Shrybman, S., "The Accord to Prohibit Bulk Water Removal – Will It Actually Hold Water?" West Coast Environmental Law, Remarks Prepared for the B.C. Freshwater Workshop, 2000.
218. Simonovic, S.P., "Managing Water Resources: Methods and Tools for a Systems Approach," UNESCO, Paris, France, 2009.
219. Simonovic, S.P., "Systems Approach to Management of Disasters: Methods and Applications," Wiley, Hoboken, New Jersey, 2011.
220. Simpson, J., "As the Sea Ice Melts, So Melts the Arctic," The Globe and Mail, October 23, 2010.
221. Simpson, J., Jaccard, M., and Rivers, N., "Hot Air: Meeting Canada's Climate Change Challenge," McClelland and Stewart, Toronto, Ontario, Canada, 2007.
222. Sprague, J.B., "Great Wet North: The Myth of Water Abundance," in Eau Canada, Ed. Bakker, K., 2007. Available at http://www.watergovernance.ca/factsheets/pdf/FS_Myth_of_Water_Abundance.pdf. Accessed on September 2, 2010.
223. Tar Sands Watch, "Canada's Water Crisis 'Escalating'; Experts Expect Climate Change to Present Serious Water Challenges, Many Already Exist," Polaris Institute, April 22, 2008. Available at http://www.tarsandswatch.org/

canadas-water-crisis-escalating-experts-expect-climate-change-present-serious-water-challenges-man-0. Accessed on October 25, 2010.

224. The Canadian Press, "Walkerton E. coli payout tops $65M but angry businesses feel shut out," in The Telegram, February 18, 2008. Available at http://www.thetelegram.com/Politics/2008-02-18/article-1441423/Walkerton-E-coli-payout-tops-65M-but-angry-businesses-feel-shut-out/1. Accessed on October 28, 2010.
225. Top 100: Canada's Biggest Infrastructure Projects, "Sydney Tar Ponds Cleanup," December 21, 2009. Available at http://top100projects.ca/2009/sydney-tar-ponds-cleanup/. Accessed on October 3, 2010.
226. United Nations Environment Programme (UNEP), "Handbook for the International Treaties for the Protection of the Ozone Layer: The Vienna Convention (1995), The Montreal Protocol (1997), Sixth edition," UNEP, Ozone Secretariat, Nairobi, Kenya, 2003.
227. US Army Corps of Engineers. "Devils Lake Basin", North Dakota, 2005. Available at http://www.mvp.usace.army.mil/fl_damage_reduct/default.asp?pageid=14. Accessed on March 8, 2005.
228. US Energy Information Administration, "International Petroleum (Oil) Reserves and Resources Tables and Reports: Most Recent Estimates," Based on Information from the Oil & Gas Journal – January 2009. Available at http://www.eia.doe.gov/international/oilreserves.html. Accessed on July 15, 2010,
229. US Environmental Protection Agency (EPA), Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup, Fourth Edition, EPA-542-B-05-001, September 2005.
230. Walters, C.J., "Adaptive management of renewable resources," McMillan, New York, New York, USA, 1986.
231. Wang, L., Fang, L., and Hipel, K.W., "Integrated Hydrologic-Economic Modeling of Coalitions of Stakeholders for Water Allocation in the South Saskatchewan River Basin", Journal of Hydrologic Engineering, Vol. 13, No. 9, pp. 781-792, 2008.
232. Wang, J., Leshkvich, G., Sellinger, C., Clites, A., and Bai, X., "Seasonal, Interannual, and Spacial Variability of Great Lakes Ice Cover in Response to Climate Change," presented at Lake Michigan: State of the Lake and Great Lakes Beach Association, Milwawkee, WI, September 29–October 1, 2009. Available at http://aqua.wisc.edu/SOLM/LinkClick.aspx?fileticket=Jg34HPGezkk%3D&tabid=74. Accessed on April 15, 2011.
233. Water Footprint Network, "Introduction," 2008. Available at http://www.waterfootprint.org/?page=files/home. Accessed on September 25, 2010.
234. Wellington, A., Burley, C., and Rollinson-Lorimer, M., "Comprehensive Chronology of Events Surrounding the Walkerton Tragedy," November 2007. Available at http://www.ryerson.ca/~awelling/documents/Wellington_Walkerton_Chronology.pdf. Accessed on October 28, 2010.

235. Weston, G., "Flushing Out Local Polluters," QMI Agency, in Toronto Sun, March 28, 2010. Available at http://www.torontosun.com/news/columnists/greg_weston/2010/03/26/13370351.html. Accessed on November 2, 2010.
236. Williams, B.K., Szaro, R.C., and Shapiro, C.D., "Adaptive Management: The U.S. Department of the Interior Technical Guide," US Department of the Interior, 2007.
237. Wingrove, J., "A dire warning from a broken pipeline," The Globe and Mail, May 14, 2011.
238. Wolf, A.T., "Conflict and Cooperation along International Waterways," Water Policy 1, 2 (1998), 251-265, in A. T. Wolf, A. T. Elgar (Editors), Conflict Prevention and Resolution in Water System. Cheltenham, United Kingdom, pp. 185-199, 2002.
239. Wolf, A.T., "Hydropolitics," Water Encyclopedia, 2010. Available at http://www.waterencyclopedia.com/Hy-La/Hydropolitics.html. Accessed on November 9, 2010.
240. Wood, C., "The Last Great Water Fight," The Walrus, pp. 26-36, October 2010.
241. Woynillowicz, D. and Severson-Baker, C., "Down to the Last Drop: The Athabasca River and the Oil Sands," Oil Sands Issue Paper No.1, Pembina Institute, Calgary, Alberta, 2006.
242. Yin, Y.Y., Huang, G.H., and Hipel, K.W., "Fuzzy Relation Analysis for Multicriteria Water Resources Management," Journal of Water Resources Planning and Management, Vol. 25, No. 1, pp. 41-47, January/February 1999.

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Laguna San Rafael Glaciers Of Chile

The Water Sector in Chile

Status and Challenges

James McPhee[1,2], Alberto de la Fuente[1], Paulo Herrera[1], Yarko Niño[1,2], Marcelo Olivares[1,2], Ana María Sancha[1], Aldo Tamburrino[1,2] and Ximena Vargas[1]

[1]Departamento de Ingeniería Civil, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile

[2]Centro Avanzado de Tecnología para la Minería, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile

1. Introduction

Chile is a country of extremes. Not only displays the greatest latitudinal range for a single country in the world (Arica, its northernmost city is located well north of the tropic of Capricorn, at 18° S, while Cape Horn is situated approximately at 57° S), but also dramatic altitudinal variations, from its coastline at the Pacific Ocean to the highest peaks of the Andes cordillera within 200 km. In part due to these features, Chile contains a wide range of climates, and thus many different hydrologic regimes. The Atacama, the driest desert on Earth, coexists in the same country with regions in Patagonia where annual rainfall in excess of 4 m is common.

Giving a comprehensive and condensed view of water resources in such a diverse country is not an easy task. This chapter attempts to provide such an overview from the perspective of water availability in quantity and quality, contrasted with the status of water resource demands. A special emphasis is given to water in cities, environmental related challenges, and issues of scarcity. Scarcity in Chile is both natural and man-induced.

The Chilean water legislation is unique in the world. While it has created wealth, it has also produced inequality in some situations. It is discussed at length in sections below. This report aims at providing first and foremost a status report. However, future challenges are highlighted with the purpose of opening discussions about the potential associated avenues of development.

2. Water Resources Availability

2.1 Surface Water

Annual mean precipitation in Chile ranges from less than 20 mm in the Norte Grande region to in excess of 6,000 mm in some areas of Patagonia. Furthermore, local elevation gradients induce orographic enhancement and rain shadow effects that result in very important spatial variability in precipitation input. Thus, surface water availability varies a great deal along the country. FIG. 1 shows the latitudinal variation of mean annual precipitation, aggregated according to administrative regions before 2007, and compares it with world and South American averages.

In the northern region, between 18° S and 29° S, scarcely any precipitation occurs at all, with most rainfall happening in the highest areas of the Altiplano (high plateau) and Andean peaks. This rainfall feeds aquifers, ephemeral streams and a few exoreic rivers such as the Lluta, San José, Loa, Copiapó and Huasco. These rivers, although modest in mean annual flow, are of extraordinary regional importance: economically, socially and environmentally. Moving southwards, precipitation increases to about 200–800 mm/year in the regions known as Norte Chico and Chile Central. These areas have typically Mediterranean climates, due to the seasonal movement of the Pacific Anticyclone, which allows wintertime precipitation and the accumulation of a dominant snowpack. Therefore, most of the rivers in this area, such as Limarí, Elqui, Aconcagua, Maipo, Rapel, Mataquito and Maule have snow-dominated hydrologic regimes with peak monthly flows in sync with peak agricultural demands; this has favored the development of a very dynamic agricultural industry in this region, which contributes approximately 5% of the Chilean GDP (Latin Focus, 2009).

Further south, in the sparsely populated regions of Patagonia and the subantarctic circle, precipitation increases significantly. Annual averages of 3,000 mm or more are not unusual, and precipitation ceases to be concentrated within a few months of the year, but occurs almost constantly throughout the seasons.

This climate gives rise to large rivers such as the Bíobío, Imperial, Bueno, Futaleufu, Aysén, Baker and Pascua; these are relatively minor when compared to other rivers in South America, but very significant in terms of annual flow for Chile. As it will be explained in later sections of this report, these rivers represent the last frontier in water resource development in Chile. FIG. 2 shows examples of the mean monthly hydrographs of characteristic Chilean rivers.

Additionally, time variability is high in most streams throughout the country. Climatic patterns such as the Atlantic oscillation (NAO, SAO, NATL) influence moisture fluxes to the arid north, whereas the central region is influenced by Pacific Ocean–related patterns, most notably ENSO. Moving south, variability decreases gradually, and rivers in Patagonia show some of the most stable regimes, in terms of annual flow, in the country. FIG. 3 gives examples of the above, by showing the

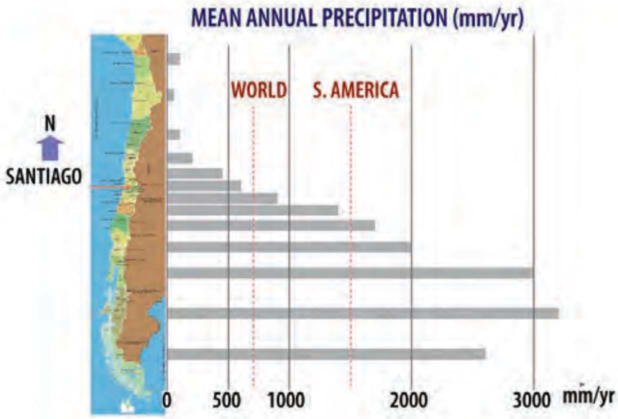


FIG. 1. Mean Annual Precipitation (mm/yr)

time series of annual flow divided by mean annual flow for three representative rivers. Panel a) shows normalized flows at the Loa river, in the middle of the Atacama Desert. The central region is represented faithfully by the Maipo River (panel b), which flows from the Andes Massif into the fertile central valley. Finally, panel c) shows normalized annual flows for the Baker River, the largest in Chile. The latter shows the least inter-annual variability among the rivers shown, with annual flows that are always within 50% of the mean. The Loa River has a different behavior, somewhat stable because of significant groundwater seepage to the stream, but also characterized for cycles of drought interrupted by wetter years. Finally, the Maipo River shows a typical behavior for central Chile, with extreme variability in annual flow from year to year, and with low frequency oscillations.

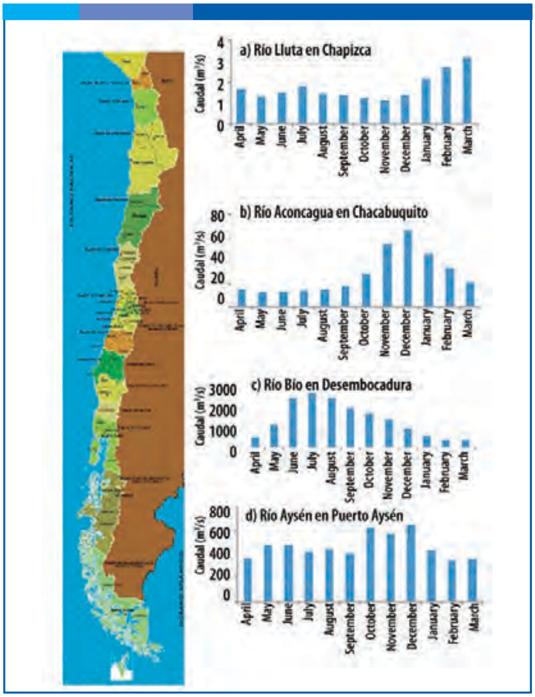


FIG. 2. Typical Mean Monthly Hydrographs for some Chilean Rivers

When computing the water balance throughout the country (FIG. 4), the dramatic differences across regions become starkly apparent. While in the northern third of Chile most water is lost to the atmosphere through evapotranspiration and evaporation from surface water bodies (e.g. Salares, wetlands), the central portion of the country displays free-flowing rivers that reach the ocean. Here, roughly one third of all available resources (4,000m³/s) evaporate to the atmosphere, while two thirds flow to the Pacific Ocean.

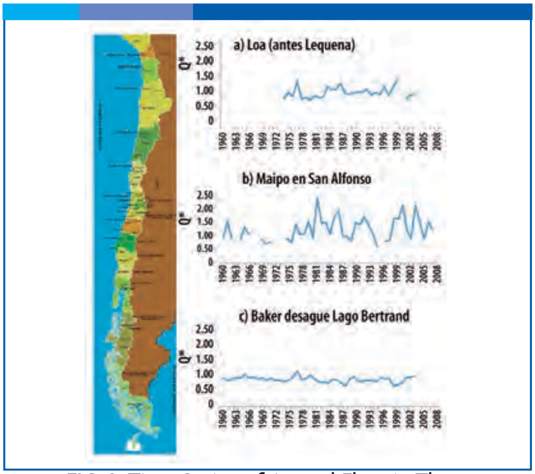


FIG. 3. Time Series of Annual Flow in Three Representative Rivers: a) Loa at Lequena, b) Maipo at El Manzano, c) Baker at Bertrand Lake

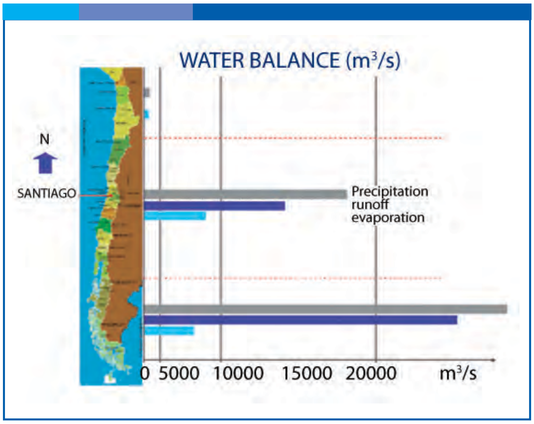


FIG. 4. Water Balance across three Regions: North, Central and Southern Chile

The southernmost third of the country, south from Chiloé Island, displays the most abundance of surface water resources.

Here evapotranspirative demands are almost fully satisfied and more than 20,000 m^3/s flow freely to the Pacific Ocean. Population density here is very low (less than 1 hab/km^2) and irrigation demands are minimal.

As stated before, spatial variability is key even when considering this rough division of the country in thirds. For instance, in Aysén, the most water-abundant region, strong longitudinal gradients due to a rain shadow effect result in coastal areas having average precipitation of more than 3,000 mm/year, whereas cities like Coyhaique, located 200 km to the east, have annual averages on the order of 300 mm/year.

FIG. 5 displays the per capita availability of water resources for those regions where this figure is relevant. The Aysén and Magallanes regions are not displayed because of the very little population.

As it follows from the previous discussion, availability increases in the southward direction. What is most interesting to note, though, is how a large portion of the country is under what has been termed water stress (Falkenmark, 1989).

This not only includes the Norte Grande zone (between parallels 18° and 25° S), but also the Metropolitan Region, where approximately 40% of the country's population lives (INE, 2008).

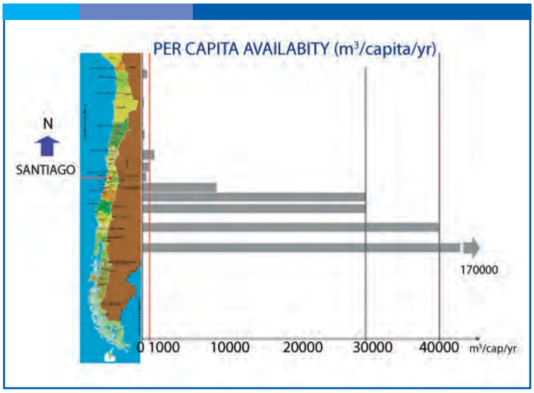


FIG. 5. Per capita Regional Water Availability. Red Line Indicates Water-Stress Threshold of 1000 m^3/inhab/year

2.2 Groundwater

Although aquifers exist throughout most of the Chilean territory, is in the northern-central region where they play the largest role as water sources for mining and agricultural activities. In general, there is limited knowledge about the horizontal and vertical extent, recharge rates and degree of interconnection of aquifers. Complex geology, with fractured rock systems and highly faulted strata, limited field data and unreliable extraction rate estimates augment the uncertainty associated with the actual sustainability of current groundwater use (Hiscock et al., 2002). In the Tarapacá and Antofagasta region, aquifers are recharged by sporadic storms originating in the Atlantic, corresponding to what is known as the Invierno (winter) Altiplanico.

Lag times of up to eight months can be observed between peak rainfall over the Atacama high plateau and peak discharges from some of these aquifers (Silva, 2010). Some aquifers seep to the ground surface at high slope areas, resulting in oases that support human settlements such as Pica, Mamiña, etc. In the Antofagasta region, recharge rates are uncertain and, in some cases, fossil groundwater may be under extraction.

Further south in the Copiapó region, existing aquifers are recharged every few years by flooding in local rivers. These episodes of high flow and subsequent recharge can be linked to inter-annual and decadal climate variability associated with ENSO –and to a less certain extent to the PDO- (Houston, 2006). FIG. 6 shows global estimates of mean annual recharge to aquifers in those regions where groundwater is most relevant.

Tarapacá, Antofagasta and Atacama regions have overall recharge rates of about 10 m^3/s, while the Valparaíso and Metropolitan regions have recharge rates between 50 and 100 m^3/s. In the latter two, groundwater resources are replenished by a combination of precipitation infiltrating to the soil, seepage from river beds during the snowmelt high flow season, and at least in the city of Santiago, by losses from the drinking water distribution system (Bartosch, 2007).

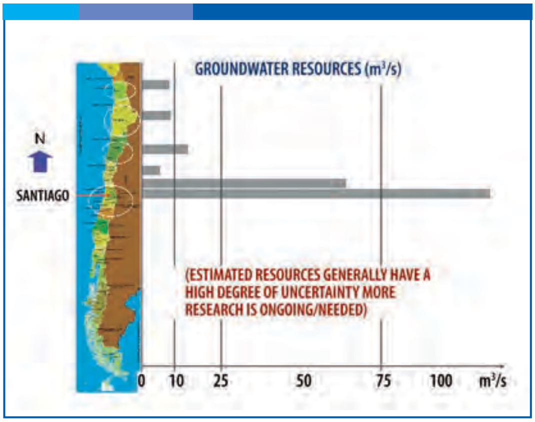


FIG. 6. Estimated Groundwater Resources as Annual Mean Discharge

Current extraction levels from aquifers in Chile may not be sustainable in some areas. The State, through the Dirección General de Aguas and Dirección de Obras Hidráulicas, is carrying out different studies in order to close this knowledge gap. Meanwhile, pressure over subsurface sources is mounting: groundwater extraction concession requests exceed by many times current estimates of available recharge. At the same time, ecosystems and human settlements that depend on groundwater seepage to survive are threatened by overexploitation (Vila et al., 2007). Therefore, it is of key relevance that research efforts directed to refining current recharge estimates be continued and supported by society at large.

2.3 Climate Change and Water

Climate change projections in Chile, although still subject to a degree of uncertainty, indicate a warming trend throughout the country, combined with a signal of reduction in precipitation for most of the north central and south central portions of the country. FIG. 7 shows the most current estimates of temperature increase for the Chilean territory.

It can be seen that variations are greatest at high elevation areas along the Andes cordillera, and that they also increase in the south direction. Precipitation trends show a 20-30% drop in annual precipitation by the end of the 21st century relative to the baseline period. This reduction affects the area between Atacama and Chiloé (23°-43° S), whereas negligible changes or even slight increases could be expected for the northern and southern extremes of the country (FIG. 8).

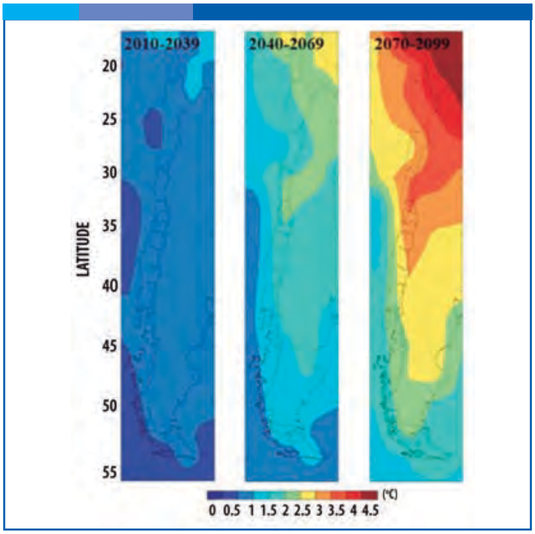


FIG. 7. Temperature Projections Under A2 Emissions Scenario. Values Expressed as Degree Changes from Base Line (1960-1990). Adapted from CEPAL, 2009

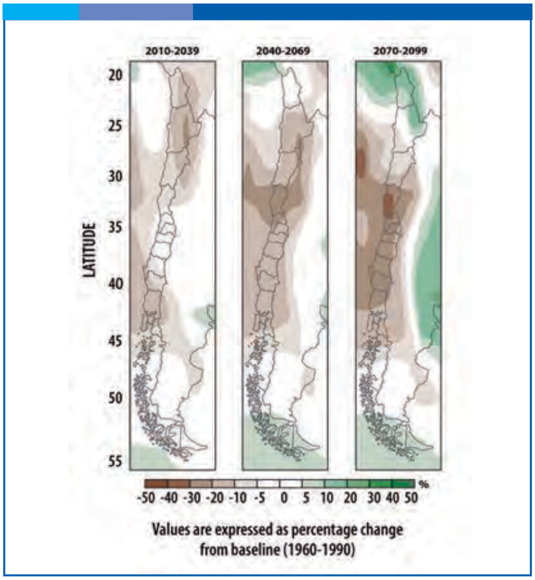


FIG. 8. Precipitation Projections Under A2 Emissions Scenario. Values Expressed as Percent Changes from Base Line (1960-1990). Adapted from CEPAL, 2009

Many studies have attempted to translate these climate projections into water-related impacts. McPhee et al. (2010) evaluated streamflow changes under temperature and precipitation changes for the 21st century, and found that high elevation, snowmelt dominated watersheds might be severely affected in their hydrologic regime and annual mean flow under the most likely climate projections. In general, percentage precipitation reductions are exacerbated by temperature increase, so that for example by 2070-2100 a 30% decrease in mean annual precipitation combined with a 1.5° C warming could result in a 40% decrease in annual flow at the mountain fronts. Current climate projections for central Chile indicate a decrease in the frequency of precipitation events, not necessarily a decrease in daily rainfall magnitudes. Combined with higher temperatures, this could result in an increased frequency of flooding events, as rain-on-snow episodes could become more significant (Perez and Vargas, 2009). Specific knowledge on this issue has still to evolve, and is limited by the scarcity of field data to feed hydrologic and flood models.

2.4 Limnology

The southern region of Chile at latitudes higher than 40oS, concentrates more than 90% of the distribution of lakes, reservoirs and lagoons (Salazar and Soto, 2006). This trend is also presented in terms of density of lakes per unit of surface shown in FIG. 9, which indicates that climatic conditions of high precipitation shown in FIG. 4 are a key factor in understanding this spatial abundance of lakes.

The nature of lakes, lagoons and reservoirs also varies across Chile. In northern Chile, water bodies are mainly salty lagoons of the Altiplano, where the upwelled groundwater is completely evaporated in a small surface (de la Fuente and Niño, 2010). In central

Chile, coastal wetlands are formed and their hydrodynamics is influenced by wind and emerged vegetation (Baladrón, 2011). Large and deep lakes formed by glaciers appear in southern Chile, among which Villarrica or Llanquihue lakes are important touristic places of the region. Stratified conditions govern their dynamics during 9 months (spring, summer and autumn), and due to the large size of these lakes, internal waves hydrodynamics is also modified by Earth rotation (Meruane, 2005; CENMA, 2006; Rozas, 2011). In spite of the large abundance of lakes in Aysén and Magallanes regions, the key agents that govern their dynamics are not well known, and this gap in the knowledge needs to be filled soon.

It is known that melted waters from glaciers feed these water bodies and strong winds recorded in the region seem to be the dominant agent that dominate their hydrodynamics; however, due to low temperatures of inflows, it is unclear whether well mixed conditions occurs in winter.

2.5 Water Quality

Water quality issues in Chile are as diverse as water quantity. Many quality problems are of human origin, but in a few areas naturally occurring constituents associated with metalogenic geological deposits (Northern Chile) represent, at best a nuisance and at worst a threat to human populations and economic activity.

The Lluta River is an example of this, where naturally occurring Boron affects local agriculture. Arsenic is one of the most conspicuous naturally occurring water contaminants in Chile. Until recently, the Arsenic standard in drinking water was 50 μg/l. Currently this limit has been lowered to 10 μg/l to match international standards. Additionally, high evaporation and increased water extractions have impacted negatively the salt content of many water bodies in the region (Vila et al., 2007).

Mining activities represent a singular problem to water quality. The Loa river (the longest river

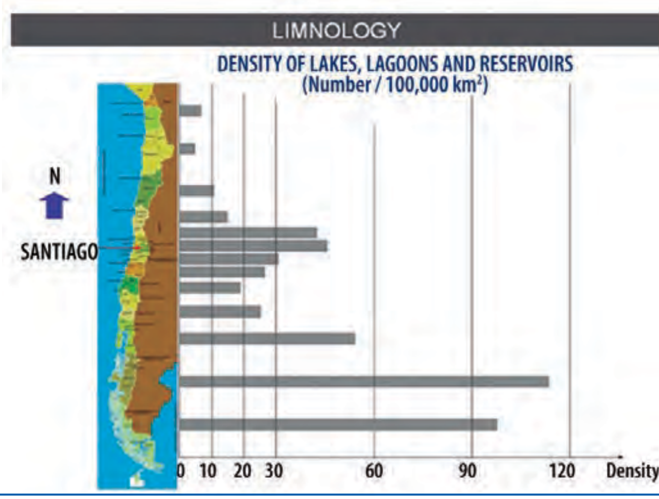


FIG. 9. Density of Lakes, Lagoons and Reservoirs [Number / 100.000 km^2] (Adapted from Salazar and Soto 2006)

in Chile) is a fair example of some of the quality issues facing northern rivers: at its headwaters in the Altiplano (high plateau) and at mid elevations, weathering of rock formations puts water in contact with mineral-rich soils and mobilizes constituents such as copper, chrome, molybdenum, boron, and aluminum. Mining activities here play an important role in determining water quality, but lack of sufficient data hampers our ability to assess its precise effect (CADE-IDEPE, 2004).

In central Chile, where agriculture represents the largest water user and most of the population resides, water quality issues are the result of disperse pollution from pesticides and fertilizers, plus organic loads from human settlements. As it will be seen later, wastewater treatment coverage has increased drastically in the last few years, thus organic matter pollution is somewhat less of a problem than it was in past decades. Regarding fertilizer and pesticide pollution, although the perception among experts is that these do represent a problem, data is limited, because so far environmental regulations in the country have dealt with controlled discharges to water bodies, and not with water quality in the receiving water bodies themselves (emission standards do exist, but environmental quality standards have not been enacted).

A significant shift in water quality issues occurs approximately at 34° S, where metalogenic formations along the Andes cordillera disappear. In turn, volcanic activity plays an important role in determining soil characteristics in basins such as the Maule River watershed, and thus the natural quality of these waters. In these, aluminum is one of the most characteristic natural constituents. Going further south, wetter conditions increase discharge rates in surface streams, thus diluting many of the municipal and industrial liquid waste discharges to rivers such as the Maule and Bíobío (CADE-IDEPE, 2004). Nevertheless, high profile pollution events (such as the Mataquito river fish mortality events) have highlighted the risks associated to the paper mill industry in an area where logging and forestry represent a major economic agent.

Water quality of lakes and reservoirs has changed due to shifts in land use and urbanization. Salazar and Soto (2006) show increased nutrients concentrations in 7 lakes whose water quality is systematically measured by DGA, a Ministry of Public Works agency. As a consequence, dissolved oxygen in the surface waters has reduced in 2 mg/l in 20 years (1980 to 2000), and recent observations in Lake Villarrica, a touristic place of southern Chile, indicate algae bloom events of harmful species during summer (V. Durán, pers. comm.), which may become human a health risk for humans with the corresponding economic looses in tourism activity. As a mechanism to revert this trend, asides the general normative that applies to all discharges, specific normative to regulate water quality of discharges to particular aquatic system is recently being defined. This specific regulation considers particular conditions of the receiving water body, and among other places, lakes Llanquihue and Villarrica defined their specific normative (Woelfl, 2010).

FIG. 10 shows, very approximately, the regional distribution of water quality issues affecting some of the main water bodies in Chile.

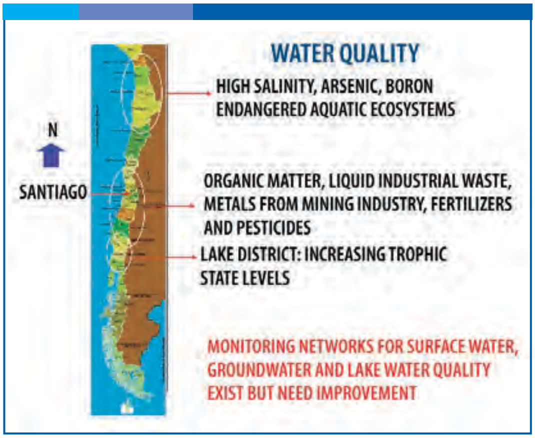


FIG. 10. Regional Distribution of Water Quality Problems

3. Water Uses

3.1 General Considerations

When considering consumptive uses, agriculture is by volume the single most important water (FIG. 11) user in Chile, representing more than three quarters of all water consumption in the country. Industry (non-mining) is the second largest user, with roughly 10% of all water consumption. Mining, with 7% of water extractions, generates the highest value in terms of GDP. This situation, together with the unique legal framework regulating water management in Chile, has resulted in water being shifted from agricultural to mining use in some watersheds. In other cases some water use has been shifted from agriculture to municipal supply, in order to keep pace with population growth and increasing per-capita water demands.

Regionally, irrigation accounts for most water uses in all but two regions north of the 40° S parallel (FIG. 12). Only in Antofagasta and Atacama mining uses represent a larger fraction of consumptive uses, due to the extreme aridity and the advanced level of mining activity in those regions. New, large mining projects under construction suggest that the trend towards increased mining use will continue, even if the mining industry sustains its current path to efficiency in water use (Section 3.6).

The central portion of the country is dominated by irrigated agriculture, with sanitation and industry representing a relevant share of water uses only in the Valparaíso, Metropolitana and Los Lagos regions (FIG. 12). Thus, even when more than 80% of the Chilean population lives in urban areas (INE, 2008), the development model followed by the country places great relevance on agriculture, and this is reflected in water use patterns.

3.2 Water, Livestock and Agriculture

As stated above, agriculture is the single largest water user (consumptive use) in Chile. Strong public policies in favor of augmenting the irrigated area were put in place since the middle of the 80's, and starting from 1990 the Chilean state pursued the objective of transforming the country in a food-producing powerhouse. Together with a consistent trend in augmenting irrigated area - the government declares an objective of 1,500.000 has under irrigation by year 2020 (MOP 2010) -, a major shift has been an increase in the value associated with agricultural production, and the ever expanding reliance in groundwater because of its superior quality, reliability and flexibility (Peña et al., 2004).

FIG. 13 shows the regional distribution of irrigated areas throughout the country and their associated water demands. It can be seen how irrigated agriculture is pervasive in Chile's central third, which may come as no surprise given its climatic characteristics. What is more striking is the fact that irrigation demands are not insignificant north of Santiago, where climate ranges from semi-arid to extremely arid.

The development of global markets for high value crops such as grapes, olives, avocado and the like has resulted in augmented agricultural demands; higher revenues allow the cultivation of hill slopes and not only valley floors; all these effects combine to drive higher demands for groundwater particularly in the sunniest (driest) regions in the country. FIG. 14 shows the irrigated areas and the average irrigation efficiency for each region of the country. Efficiency is worst in the central region, where water resources are still perceived as abundant and alfalfa as well as other livestock plant foods is predominant. In the northern part of the country efficiency increases to between 45% and 60% driven by water scarcity and high value crops that allow higher investment in irrigation systems.

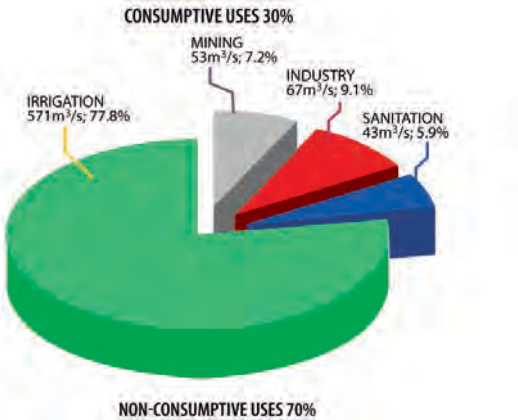


FIG. 11. Distribution of Consumptive Water Uses

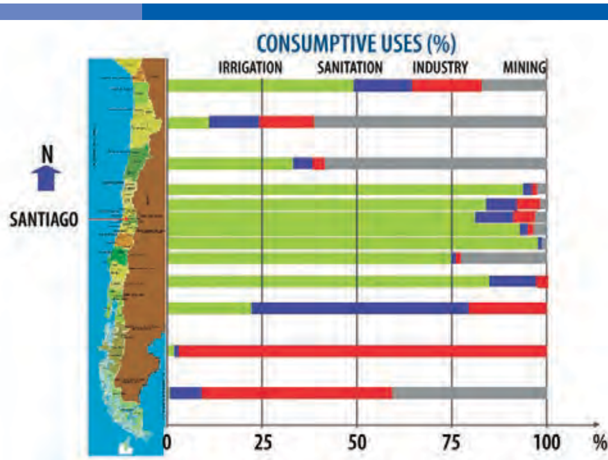


FIG. 12. Consumptive Uses, in Percentage

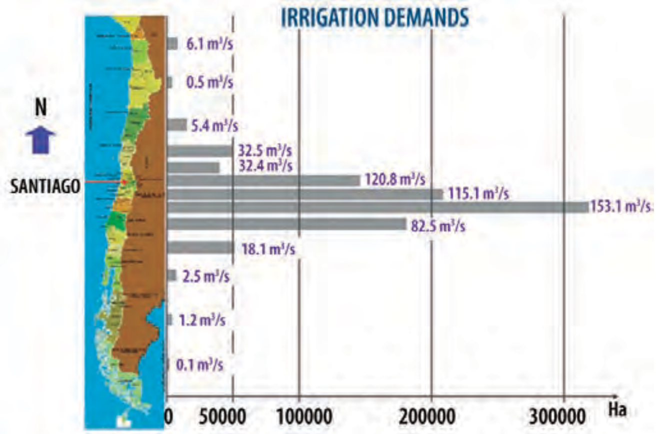


FIG. 13. Irrigated Areas in Chile and Associated Consumptive Use

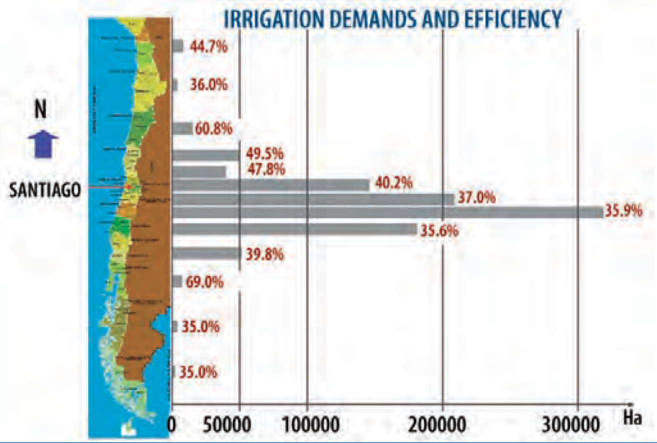


FIG. 14. Irrigated Areas in Chile and Associated Irrigation Efficiency

3.3 Water and Ecosystems

Chile combines a relatively low population with remote regions and a wide range of climates and this combination results in many areas where ecosystems remain largely pristine. In addition to national parks and national monuments, which in many cases feature water bodies prominently, Chile is affiliated to the Ramsar Convention, and thus wetlands in the country have special status. Wetlands, albeit protected, are fragile ecosystems that in many occasions are surrounded by human activity: well exploitation for industrial purposes, agriculture, grazing and logging can have detrimental effects over water recharge, chemical inputs, sediment loads and other factors determining ecosystem health.

In Chile, Ramsar sites have gained increased attention in the past decade, and the Chilean public nowadays shows awareness, if not about the specific details, about the relevance of the issue. A key factor in this process was the incident involving the *Carlos Anwandter*

Sanctuary, where swans mortality was associated with irregular industrial wastewater from a paper mill. This case received intense media coverage and prompted several technical reports. To date, disputes on the origins and responsibility about the incident remain active (Muñoz, 2005).

Table 1 lists the Ramsar sites managed by the national agency in charge of national parks and reserves (CONAF); wetlands in Altiplanic Salares are the majority, but also included are coastal lagoons and riparian habitats. Table 2 lists Ramsar sites managed by other entities. The first two sites are coastal lagoons located in the extreme south (Bahia Lomas) and semi-arid center-north of the country (Laguna Conchali). The third (Juncal) is a recently added site located in a high elevation valley in the semi-arid Andes, two hours north of Santiago.

3.4 Water Services for Municipalities

The analysis of municipal water services in Chile must be separated into small localities (less than 500 connections) and large localities (more than 500 connections). The municipal water sector in Chile underwent a gradual but steady transformation since the decade of 1970, where the State slowly opened spaces for private investment in the sanitary sector. Currently, the Chilean state exercises an exclusively regulatory role through the Superintendencia de Servicios Sanitarios (SISS), while drinking water production, distribution and wastewater collection as well as treatment (in large localities) are responsibility of private companies. These companies constitute natural monopolies in their service areas, so the State controls service quality and tariff setting through a precisely defined negotiating process. The State keeps

Table 1. Ramsar Sites Managed by CONAF

Site	Coordinates	Surface area (has)	Aditional protection	Wetland type
Salar de Surire	18° 46’ to 18° 55’ S and 68° 58’ to 69° 06’ W	15,858	Natural Monument	Perennial salty lagoons associated to altiplanic salares
Salar de Huasco	20° 18’ S ; 68° 50’ W.	6,000	National Park	Perennial salty lagoons associated to altiplanic salares
Salar de Tara	23° 01’ S; 67° 18’ W	5,443	National Preserve	Perennial salty lagoons associated to altiplanic salares
Sistema Hidrológico Soncor	23° 15’ to 23° 22’ S and 68° 07’ to 68° 11’ W	5, 016	National Preserve	Perennial salty lagoons associated to altiplanic salares
Salar de Pujsa	23° 11’ S; 67° 32’ W	7,397	National Preserve	Perennial salty lagoons associated to altiplanic salares
Aguas Calientes IV	24° 59’ S ; 68° 38’ W	15,529	None	Perennial salty lagoons associated to altiplanic salares
Laguna del Negro Francisco y laguna Santa Rosa	27° 27’ S and 69° 13’ O and 27° 04’ S and 69° 10’ W	62,460	National Park	Perennial salty lagoons associated to altiplanic salares
El Yali	33° 50’ S ; 71° 36’ W	520	National Preserve	Coastal, lagoon
Santuario de la Naturaleza Carlos Anwandter	39° 35’ to 39° 47’ and 73° 07’ to 73° 16’ W	4,877	Nature sanctuary, Montreux Registry	Perennial riparian with periodic tidal effects

a minority stake in most of the companies that currently operate in the country, while special regulations control the participation that any single firm may have in a geographic region. In order to keep expenditures in basic services in check for poor segments of the population, the State issues targeted subsidies that cover a percentage of sanitary services monthly bill. In small localities, local committees (rural potable water committees), which receive technical and some financial support from the State, manage water production and distribution. These committees operate autonomously and are composed by the residents of the area being served. Usually composed by a groundwater well, a chlorination unit, an elevated tank and a PVC distribution network, about 1,000 such systems exist in the country, and they have been enormously successful in providing safe drinking water for isolated towns and villages. Some challenges remain, though, as these small systems are vulnerable to drought or other emergencies, and lack financial resources to invest in increasing their supply security.

FIG. 15 shows the amount of potable water produced across Chile's territory. The supplied rates are rather homogeneous with the salient cases of cities such as Valparaíso-Viña and Concepción (with almost 5 m^3/s) and Santiago, with more than 20 m^3/s. This chart mirrors closely the population distribution in Chile, but amplifies this factor by climatic effects (Santiago is located in a semi-arid region) and economic factors. In Santiago, where average income is generally higher than in other cities, per capita consumption (230 l/cap/day) almost doubles that of the rest of the country (110-150 l/cap/day). Not shown is this graph is the very high spatial variability of per capita consumption within cities: in Santiago, this metric can be as low as 150 l/cap/day –proper of cities located in very arid regions such as Antofagasta-, but as high as 600-800 l/cap/day at the wealthier areas of the city. Non-critical uses such as yard irrigation and swimming pool filling account for this large difference. As stated above, successive Chilean governments implemented policies allowing for private capitals entering the sanitary sector. Leaving aside political considerations, this process injected fresh resources to regional utilities, and these resources allowed for: a) the almost complete coverage of supply and sewage collection systems along the country (FIG. 16), and most importantly, for b) a dramatic increase in the coverage of sewage treatment. FIG. 17 shows this metric, and it is self-evident how, around years 1998-2000, the sanitary sector experienced a systemic transformation that led to an almost complete coverage of wastewater treatment today.

Table 2. Ramsar Sites Managed by Other Parties

Site	Coordinates	Surface area (has)	Aditional protection	Wetland type
Bahía Lomas	68° 49' to 69° 26' and 52° 27 to 52° 32'	58,946	None	Coastal, with large tidal flats
Laguna Conchalí	31° 53' S ; 71° 30' W	34	None	Coastal, transitional
Parque Andino Juncal	32° 55' S; 70° 03' W	13,796	None	Alpine spring fed

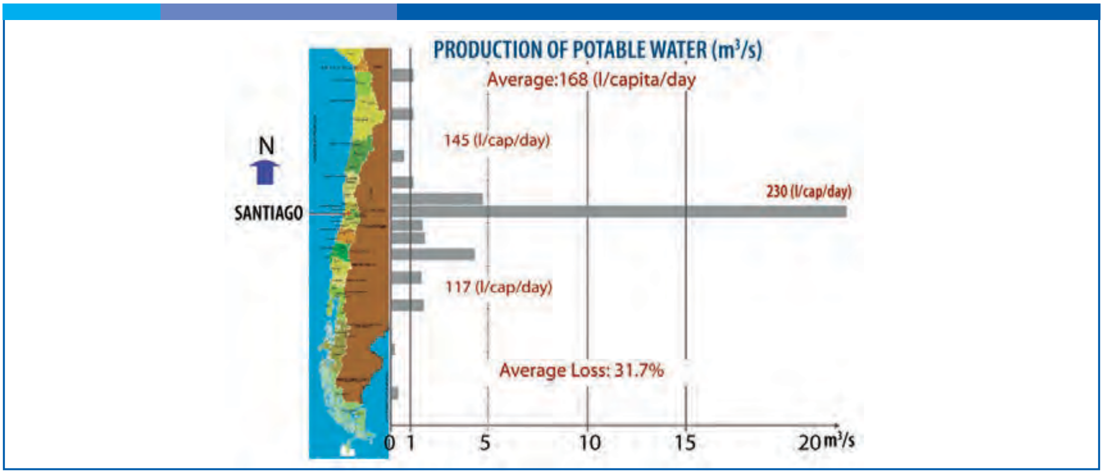


FIG. 15. Municipal Water Production and Average Per capita Design Rate.

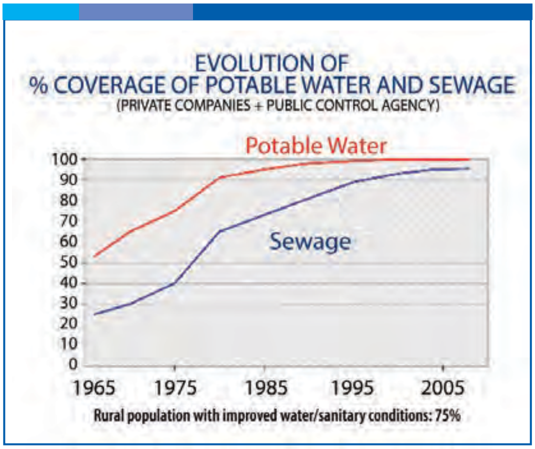


FIG. 16. Historical Evolution of Sanitary Sector Coverage

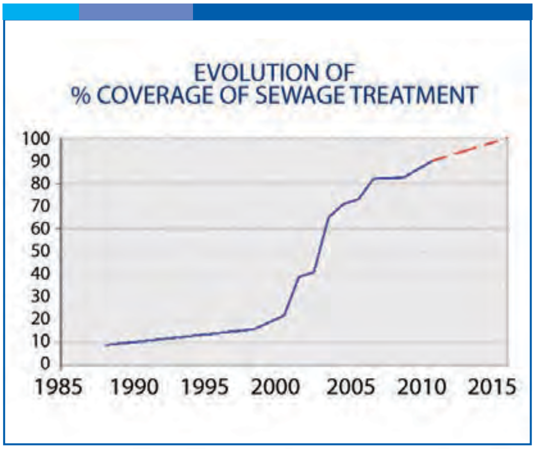


FIG. 17. Historical Evolution of Sewage Treatment.

Despite these remarkable advances, challenges remain for the sanitary water sector: utility companies' service areas usually evolve at a slower pace than urbanization, so there are cases that human settlements adjacent to "urbanized" areas lack adequate water services. Legally, these settlements are considered "rural" or "peri-urban", and water utilities are not forced to incorporate them to their service area, with the resulting inequity in water supply and sewage services. On the other hand, in rural areas, where cooperative, community-managed systems operate, financial limitations preclude supply robustness, and sanitation services are not included in the responsibilities of municipalities or local utility management committees.

3.5 Water and Health

The investments in sanitation by the Chilean State and private companies described above led directly to greatly improved morbidity and mortality indices of water-borne or water-related diseases. In fact, Chile shows children mortality rates comparable with those of developed countries, which can be traced to improved socioeconomic conditions, among which access to safe drinking water and sewage are key.

On the other hand, high exposure in Chile´s north to arsenic during 1950-1970 produced early health effects, including increased rates of infant mortality. An epidemiological study conducted in 1994-1996 generated data on arsenic exposure and death rates from cancers of the lung, bladder, kidney and skin for the period 1950-1996. The authors of the study conclude that the most significant public health effect of the presence of arsenic in drinking water was lung cancer (Ferreccio et al., 2002). The high risk for lung cancer in Antofagasta persisted for 20-30 yr after operation of water treatment plants, built to remove arsenic, began. From 1993 to 2002 the risk of dying from bladder or lung cancer in Antofagasta was four and seven times higher respectively, than in the rest of Chile (Ferreccio and Sancha, 2006).

These rates are expected to decrease, in the coming years, because of significant diminution of arsenic concentrations in drinking water. However, the impact of increased arsenic emissions into the atmosphere- mitigated somewhat by trapping of gases in recent years- may have negative consequences in the coming decades (Sancha and O´Ryan, 2008).

3.6 Water and Industry

In terms of economic output, mining is the single most important industrial use given to water in Chile. Combined, all mining activity generates approximately half of Chile's exports. Most mining activities are concentrated in the northern half of the country, where climate varies from extremely arid to semi-arid. As such, even the relatively modest water demands that mining industry exerts over the national water balance become relevant at a local level. Because in many areas mining has developed later than other long-standing water uses (such as agriculture), transfers of water rights from these historical uses to mining has created problems in the water balance of many watersheds. Conversely, the mining industry has made significant progress in reducing its fresh water use; currently the average for the industry is 0.75 m^3/ton Cu (Table 3), which at a price of US$3.00/ounce Cu is equivalent to an economic output of approximately US$1,400/ liter of fresh water.

The long-term efficiency goal stated by the industry is 0.50 m3/ton Cu, which represents a recirculation ratio of approximately 4-5 (FIG. 18).

FIG. 19 shows the non-mining industrial consumption in Chile, distributed geographically. The most important industries in this respect are the paper/pulp processing industry, metallurgic and food processing.

Table 3. Mining Water Uses for Different Processes

Process	Current Consumption (m^3/ton Cu)	Goal (m^3/ton Cu)
Concentration	1.10 (0.40-2.30)	0.60
Hydrometallurgy	0.30 (0.15-0.40)	0.25
Other	0.10	0.05
Average	0.75	0.50

Source: Global Water Partnership, 2004

As can be seen from the illustration, the demands are concentrated in the central portion of the country, especially in the Maipo, Maule and Biobío river watersheds. The latter concentrates a great deal of the paper mill activity in the country, and as was discussed above, can have detrimental effects on water quality associated with accidental leaks of solvents, byproducts, etc. (Gaete et al., 2005).

3.7 Water and Ecotourism

In Chile, the concept of ecotourism has been superseded by that of special interest tourism (SIT). According to the National Tourism Service (SERNATUR), in 2008 approximately 2,650,000 foreign tourists entered Chile, and of those 70% did so attracted by special interest activities. SIT does occur in areas where water bodies play a predominant role in shaping the landscape, such as in Patagonia, the lakes district and salares in Northern Chile. In some of these areas, water is key for either conserving unique biological species (e.g. Flamingo populations in the Altiplano), or for integrating a pristine landscape (e.g. Patagonia), or as a sustain medium for a highly valued activity, such as fly-fishing at many fishing lodges in Southern Chile.

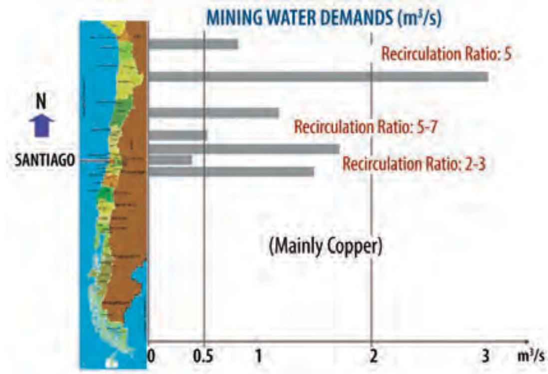


FIG. 18. Mining Water Demands in Chile, and Associated Recirculation Ratio

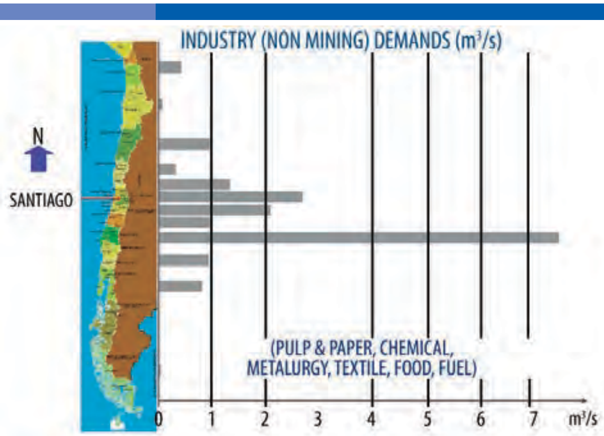


FIG. 19. Water Consumption for Non-mining Industrial Uses

Chile has 9,140,330 has of National Parks, 5,402,669 has of Natural Reserves and 26,896 has of Natural Monuments. Additionally, the Ramsar sites are associated specifically with wetlands and are destinations associated with ecotourism, (Section 3.3).

3.8 Water and Energy

The relationship between water and the energy sector is manifold. Apart from being essential in hydropower generation, large amounts of water are used for cooling purposes in thermal plants. When used for cooling purposes, water is returned to the environment at high temperatures, with the potential damage to sensitive ecosystems. Despite its importance in thermal power generation and due to data availability, this section will focus on hydropower production.

FIG. 20 shows the contribution of each generation technology to the national installed capacity for 2007 (Palma et al., 2009). Hydropower accounts for about 38% of the 12,847 MW national installed generation power. This share can be further decomposed into 27% of hydropower reservoir plants, 10% of large run-of-river, and 1% of small hydropower plants, which are defined here as having a generating power equal or smaller than 20 MW. Hydropower's contribution to the national installed capacity is almost exclusively concentrated in the Central Interconnected System (CIS), the largest of the four grids that conform the Chilean power system (FIG. 21).

The Norte Grande Interconnected System (NGIS) and the much smaller Aysén Interconnected System (AIS), have 13 MW and 20 MW of small hydropower capacity,

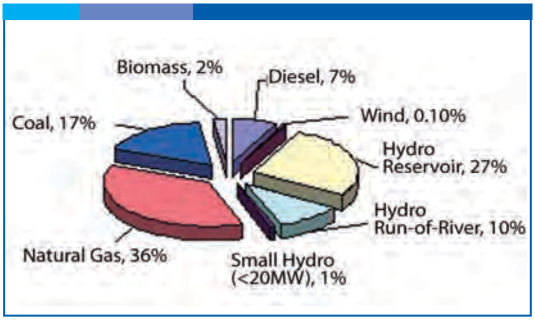
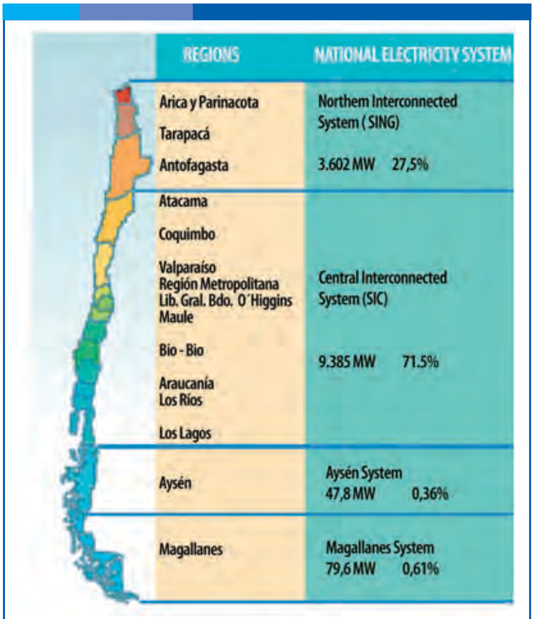


FIG. 20. Electric Power Generation Matrix in Chile, 2007 (Modified from Palma et al., 2009)

respectively (Palma et al., 2009). The dynamics of hydropower's relative contribution to the CIS installed capacity are shown in FIG. 22. This evolution can be explained to a great extent based on alternative fuel availability and prices. When fuel prices are relatively low, investments in hydropower new projects are postponed, increasing the share of thermal power. Given the expected global scenario for fuel prices, investment in hydropower plants should reactivate in the coming years. Additionally, as a means to promoting electricity generation from renewable sources, a law was passed in 2007 which enforces a share of the energy sold by companies to end-users must come from renewables (including small hydro). Specifically, the law enforces a share of 5% between years 2010 and 2014, and yearly increases of 0.5 % to reach 10% by year 2024. Due to this legal change, a as of December 2008, over 230 MW of small hydropower projects were under environmental assessment and many more are expected in the near future.

A remarkable feature is that both the water and the electricity sector have undergone free-market reforms resulting in a scheme under which private agents are responsible for investment decisions. In this context, a question arises about the right balance between markets and regulation, particularly when climate change will make water-energy interactions more critical than in the past (Bauer, 2010). Despite the large contribution to the current CIS installed capacity, hydropower potential is far from exhausted. Untapped potential concentrates in the southern areas, mainly Patagonia, where controversial, large hydropower projects accounting for about 3,000 MW are currently undergoing environmental assessment (FIG. 23).



SOURCE: PALMA ET AL. 2009

FIG. 21. Chile's Four Interconnected System

3.9 Water and Transportation

Because of Chile's singular geographic characteristics, Chilean rivers are generally unsuitable for navigation, and do not provide significant transportation means. Some exceptions exist in the central-south region of the country, where increased precipitation

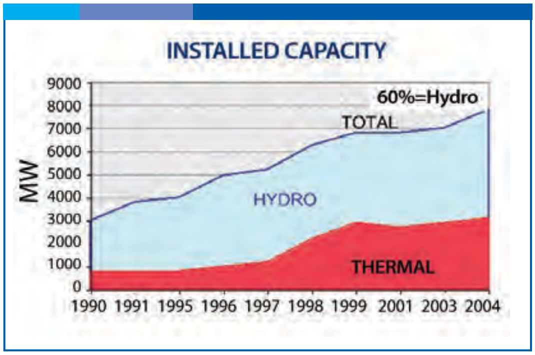


FIG. 22. Share of Hydropower in Chile's Central Interconnected System Energy Matrix

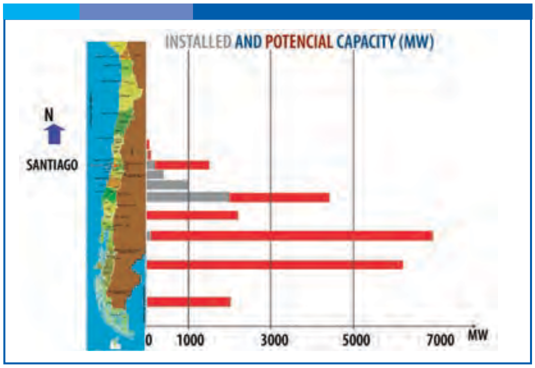


FIG. 23. Hydropower Potential and Installed Capacity

and flatter topography results in larger, broader and deeper rivers where local traffic of people and goods can occur. Notable in this respect are the Biobío, Toltén, Bueno and Calle-Calle rivers.

In the Lake District, some lakes provide routes to towns near the border with Argentina, in fact becoming part of international routes. This is the case of the Pirihueico, Todos Los Santos, and General Carrera lakes.

3.10 Aquaculture

Aquaculture has been one of the most dynamic industries in Chile during the last two decades, to the point of making Chile the eighth (in weight) producer of cultivated fish in the world, with more than 650,000 tons (FAO, 2005).

Economically, aquaculture has even surpassed fisheries in exports values, representing more than half of the total output of this sector.

Although the bulk of aquaculture activity takes place in fjords, estuaries and protected marine channels in southern Chile, some stages of fish development and a not-negligible fraction of this industry do occur in fresh water bodies, particularly in lakes. Aquaculture has been associated with a detrimental effect in water quality, because of eutrophication due to food losses and concentrated feces from fish crates. Also, a yet unquantified amount of vaccines, antibiotics and other chemical compounds applied to fish become available in the water column. The overall environmental effect of these variables has not been accurately quantified, but many authors point the environmental costs associated with Salmon and Trout production in Chile (e.g. Buschmann and Fortt, 2005; Cabello, 2004).

4. Water and Society

4.1 Urban Water

Following a global trend, in 2010 more than 80% of the Chilean population lived in cities (INE, 2008). This creates challenges and opportunities associated with water supply and services on one hand, and with risks and hazards on the other. Many of the issues related to sanitation are discussed in the section above. With respect to water related hazards, the Government has pursued an ambitious infrastructure plan in order to control and mitigate risks due to flooding, debris flows and other phenomena. Sometimes the impact of these events is local, circumscribed to areas adjacent to intermittent flow creeks and gullies. In other cases, the effects of flooding affect larger urban areas. The technical model adopted in Chile for dealing with this problem usually relies in centralized management of excess runoff through collecting systems that converge to main evacuating channels. Table 4 shows the projected investment in urban storm water drainage until 2020. Although pilot projects proposing decentralized storm water management have been proposed and research has shown some of the advantages of this alternative approach (e.g. Parkinson and Mark, 2005), by and large the model of centralized drain systems is still the dominant technical alternative for dealing with this issue. The last couple of decades, social awareness of debris flows has increased in Chile as a result of catastrophic events that have taken place along the country. This awareness, joined to the knowledge of control measures used in other countries, have induced successive governments and private companies to develop several projects to reduced the damage generated by debris flows (Hauser, 2004).

Although the biggest, and most cost demanding, debris control works have been built in the last twenty years, there exist many small works designed for debris flow local control that date from earlier periods. For example, masonry and rubblework check-dams were built in Valparaiso in 1940, in order to control and capture the sediment carried during debris flow events in the main ravines reaching the urban area (Hauser, 2004). Gabions have also been used to construct check-dams, like the one located in Los Piches Creek, Metropolitan Region (FIG. 24). Check-dams built with timber logs and filled with large stones, called "quinchos" have been used to arrest the sediment transported by debris flows and prevent channel erosion in Coyhaique, in the south of Chile. Although this area has records of debris flows at least since 1928, systematic studies and protection works started after a severe event in 1966 (Hauser, 2004). In the last years, check-dams constructed assembling pre-fabricated concrete joists and filling them with boulders have been built (FIG. 25). In the last two decades large control infrastructure works have been built in vulnerable areas along the country as a governmental reaction to several catastrophic events that occurred in the 1990's, involving dead and missing people. The level of risk associated with this type of events has increased steadily with time, because foothills and hillsides have been occupied due to urban growth. Thus, after a debris flow event in the city of Antofagasta (1991), in which 119 people perished and infrastructure was seriously damaged (C.R.H., 1993; Ayala, 1996; Hauser, 2004), the Ministry of Public Works built a series a check-dams in 10 ravines (MOP, 2009), (FIG. 26). In May 1993, intense rainfall combined with high temperatures in high mountain areas affected the central region of Chile, causing debris flows in an extended area. The city of Santiago was particularly affected, with 34 fatalities and over 5,000 houses damaged. As a reaction, seven sedimentation

Table 4. Projected Public Investment in Urban Drainage 2010-2020 (MM$). Includes Planning, Construction and Maintenance

Program	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total (MM$)*
Master Plans in cities over 20,000 inhab.	0	200	800	800	800	800	600	0	0	0	0	4,000
Design & execution of works in cities over 20,000 inhab.	0	0	0	400	1,000	17,000	17,000	21,000	21,000	24,600	24,000	126,000
Design & execution of works in cities over 50,000 inhab.	20,500	23,000	21,500	17,000	16,000	8,000	8,000	8,000	8,000	7,000	7,000	144,000
Development of strategic frameworks in order to make new Laws about Rainwater.	0	1,200	900	900	900	600	500	0	0	0	0	5,000
Policy Studies of rainwater	200	200	100	0	0	0	0	0	0	0	0	500
Maintenance of the urban storm water drainage	2,200	2,400	2,500	2,600	2,700	2,800	3,000	3,000	3,200	3,200	3,400	31,000
TOTAL	22,900	27,000	25,800	21,700	21,400	29,200	29,100	32,000	32,200	34,800	34,000	310,500

Source: Dirección de Obras Hidráulicas, Ministerio de Obras Públicas
* Currency 2009

FIG. 24. Check-dam Built with Gabions

FIG. 25. Check-dams Constructed with Pre-fabricated Concrete Joists

FIG. 26. Panoramic View of Chek-dams Built in Ravines El Ancla and Baquedano, Antofagasta (MOP, 2009)

basins were built in Quebrada de Macul, a ravine that experimented the largest flows (see FIG. 27). Similar sedimentation basins were constructed in Copiapó, a city in the north of Chile, which in June 1997 suffered the action of strong debris flows, generating heavy economic losses. It is interesting to note that people living in the neighborhood of the sedimentation basins have taken care of them, transforming them into soccer fields, thus helping to keep the basins clean.

4.2 Hydroeconomy

The development strategy followed by Chile in the past 30 years has been one of increased private initiative and the development of mining, agriculture, aquaculture and forestry as the major drivers of Chilean economy. As such, water has seen its relevance increase as an intermediate production factor for many industries. Probably one of the main challenges facing Chile to this date is the insuring of adequate energy supply in order to sustain the level of economic growth displayed by the country in the past decades. In this scenario, hydropower rises as the only renewable, large-scale energy source currently able to compete economically with coal and diesel power plants. The environmental impact of large hydropower projects (both dammed and run-of-river) has been intensely debated, and no national consensus exists yet regarding the most sustainable strategy for energy production. However, it is likely that hydropower projects (large, medium and small sized) will continue to be designed and built

4.3 Institutional and Legal Framework

In Chile, the main governing legal body for water management is the 1981 Water Code (with modifications in the 2005, 20.017 Act.). The Water Code indicates that Chilean continental water as public-use, national goods, but assigns water rights to private parties who can make use of them as with any other private property. In other words, water in Chile is a public good until it is assigned, via water rights, to an individual or company; then it becomes governed by private property principles. Water in Chile is dissociated from land, so water rights can be bought, sold and rented without much consideration of their initial purpose.

SOURCE: A) DIRECCIÓN DE OBRAS HIDRÁULICAS, MINISTERIO DE OBRAS PÚBLICAS.
B) HAUSER, 2000.

FIG. 27. Sedimentary basins. A) Aerial view of the sedimentary basins in Quebrada Macul, Santiago. B) Basin of sedimentation transformed by the community in soccer field.

The 1981 Water Code is inspired notoriously by a liberal view of natural resource management, which gives preeminence to the economic value of water resource as a final good or as an intermediate resource for economic activity. It purports the creation of water markets, and is inspired by the notion that these markets would allocate resources in an efficient manner, to the most profitable uses. As such, the code minimizes the role of the State in planning and managing water resources, and gives a government agency the responsibility of issuing water rights over a water body (aquifers or streams) when they are requested and hydrologic availability is proven.

From its inception, the 1981 Water Code was criticized for adopting an extremely ideological view of water issues, with little regard for the specific characteristics of the broad range of river basin characteristics that can be found in a country as diverse as Chile. Starting in 1990, with the taking over of the government by center-left political parties, and also due to mounting evidence of the inadequacy of markets alone for dealing with water management in combination with social and environmental issues, small steps were taken in order to correct aspects of the law.

The main problems identified involved the lack of regulation to insure that beneficial uses where given to newly issued water rights; in fact, between 1981 and 1990 many water rights issued to hydropower companies were not translated into economic activity but were used as speculative tools, hindering the very economic activity that the Water Code was intended to foster.

Additionally, the original version of the Water Code did not acknowledge the connection between surface and groundwater; in effect establishing parallel, independent markets in physically connected hydrologic systems.

A 2005 modification of the Water code aims at correcting some of the above distortions by requiring solicitants of new water rights to justify the amount of water requested in relation to an intended use.

Also, it establishes fees for not using water rights in order to avoid speculation (although some times these fees are low in comparison with the potential benefits of speculating), recognizes the relation between surface and groundwater, and for the first time establishes the concept of in-stream flow requirements.

The in-stream flow, unfortunately, only applies to water rights issued after the 2005 law modification. Because by 2005 a majority of rivers in Chile were fully allocated, most of the rivers in the country are not associated with in-stream flow requirements.

Other legal bodies that apply and complement the Water Code include:

- Indigenous Population Code: establishes subsidies intended for supporting indigenous people or communities in buying water rights, and recognizes ancestral uses given by these communities to water bodies.
- Sanitary Code: regulates the activities of water utilities, including the required investments in infrastructure and tariff setting.
- Environmental Code: establishes the Environmental Impact Assessment process.
- 18.450 Irrigation Act: sets loans and other forms of funding in order to increase the irrigated acreage and improve efficiency in water use for agricultural purposes.

Institutionally, the agencies with responsibilities pertaining to the water sector include:

- Dirección General de Aguas (Ministry of Public Works, DGA): with the mission of researching and managing water resources. It issues water rights, maintains the main hydrometeorological monitoring network in the country, including groundwater levels, sediment loads and water quality. DGA is also in charge of enforcing the water code in relation to water extractions from streams and aquifers, as well as approving the construction of medium sized to large infrastructure projects.
- Dirección de Obras Hidráulicas (Ministry of Public Works, DOH): DOH plans and executes projects associated with water management such as irrigation reservoirs and distribution networks, storm water drainage, fluvial infrastructure; it also provides technical assistance to rural water supply systems.
- Superintendencia de Servicios Sanitarios (SISS): This agency is in charge of regulating the operations of water utility companies; in addition to monitoring industrial wastewater discharges to water bodies. The utility regulation component of its functions includes tariff setting, definition of concession areas and general overview of utility companies' operations.
- Sistema de Evaluación de Impacto Ambiental (Ministerio de Medio Ambiente, SEIA): This agency coordinates and oversees the environmental impact assessment process.

4.4 Water and Woman

Chile, as the rest of Latin America, has been working for several years on including more strongly a gender focus in water management. In particular, access to water for all is a goal that has been on the government agenda for more than 40 years when the Rural Water Program (APR, in Spanish) was established. The APR program involves small supply and distribution systems serving small communities. Each system is self managed in a cooperative mode, with technical assistant from DOH, a government agency. Is in this field where women have had the greatest opportunity to become relevant agents of change and active stakeholders on water issues. Throughout the country, women participation is over 80% in the administrative aspects of rural water systems; their presence in executive boards decreases to 34%, and only 4% of women participate in the operation of these systems.

Within the APR system, women have been able to shift from a management paradigm focused only in covering operational costs to one centered in efficiency, establishing fees that take into account the real operational and maintenance costs of rural water distribution systems. Women participation on science and technology in Chile is limited (Rebufel, 2009), but their participation in developing knowledge for water management is relevant. In this sense it is important to promote associations and synergy among professionals of technical and social fields working on water issues.

Women tend to think on a sustainable way so they care about the impact on the environment and water resources minimizing the effects of human activity. As an example of this, the INEH (Iniciativa de Eficiencia Hídrica, ww.ineh.cl) initiative initiated on 2008 at Dirección General de Aguas of the Ministery of Public Works, is formed mainly by women professionals; through teamwork they have formulated proposals for water resources policies as well as clean and efficient domestic water technologies (M. A. Alegría, pers. comm.).

4.5 Public Participation

The institutional framework for water management in Chile, as described before, is one in which water right holders operate water markets that are expected to allocate optimally the resource to the most efficient uses. Public participation is contemplated in the Water Code by the definition of users associations: a channel users association groups all users from a single primary channel; a junta de vigilancia groups water rights holders from the same stream; a comunidad de aguas subterráneas, brings together everyone with water rights to the same aquifer. In all these cases, the people participating in these associations must all be water right holders.

When water issues intersect with environmental or social issues, though, this model becomes inadequate, as stakeholders in environmental water related problems might not hold water rights. According to Chilean law, then, these stakeholders are not valid participants in debates involving water planning and management. On the other hand, the Environmental Impact Assessment System (SEIA) contemplates an instance of public participation associated with the assessment process of individual projects. In this case, at certain times during the assessment period, town hall meetings are held in which the project developer presents the project to stakeholders and public comments are recorded and organized. Thus, public participation for water issues occurs only if there is a specific project being environmentally assessed, and if this project affects in any way the local water bodies.

Other instances of public participation include the rural drinking water committees, in which the inhabitants of a locality operate and manage their own distribution system; in territorial planning, whereby land-use plans are publicly discussed, water issues such as construction in flood prone areas might provide further space for discussion.

5. Conclusions

This chapter reviews some of the main water issues and challenges facing Chile, in relation to human, environmental and geographical dimensions. The development of the water sector in Chile has been strongly influenced by a decisive transition to economically liberal policies, where private investment has a primary role and State participation is limited to regulatory and oversight functions. The 1981 water code separated water rights from land ownership, and emphasized the value of water as an economic good.

Although this transformation added significant dynamism to the productive sector, and arguably contributed to the economic growth experienced by Chile in the last decades of the 20th century, it has also generated some problems that the Chilean State has attempted to correct since 1990. These problems are mostly related to the functioning of water markets in terms of speculation, monopoly and inequity in access to water for disadvantaged groups of the population.

The environmental value of water and the ecosystem services associated with aquatic systems were absent from the original water code, but have slowly gained preponderance in the public discussion and in the assessment of investment projects, through the environmental impact assessment system.

Now the economic aspects related to water management have been firmly established and accepted by most stakeholders, the water sector should strive to balance these aspects with environmental and social sustainability.
The Chilean population, for the most part, has adequate access to water services (supply and sanitation).

Again, government policies have favored the participation of private companies in the ownership of water utilities, while the state has maintained a strong oversight role.

This has had as a result, a sharp increase in drinking water, sewage and wastewater treatment coverage since the 1990`s decade. Improved sanitary practices have all but eradicated water-related diseases in Chile, but concerns remain about the presence of naturally occurring elements, such as Boron and Arsenic, in water sources in the northern portion of the country.

In terms of water use as an intermediate economic good, the situation is diverse among industries: irrigated agriculture remains by far the largest (in volume) user of water in the country, with application efficiency levels in the order of 50% as a national average.

No estimates of the importance of "involuntary recycling" (i.e., use of irrigation excess water by downstream users) exist, but at the watershed level it can be supposed that overall efficiency is a little higher. Mining, on the other hand, is the industry that extracts the most economic value per unit volume of water, and this is reflected by and large by the cost of water transactions (willingness to pay) in this industry.

At the same time, most mining activities in Chile develop in arid or semi-arid regions, so the impact of new extractions or, conversely, water savings, can be high for ecosystems and local populations.

Water quality problems related to agricultural, industrial and mining activities have been acknowledged for some time, but these problems have become more visible in the last few years due to high profile pollution cases that have resulted in increased public awareness. Chile shows a somewhat coherent, technically proficient institutional framework for dealing with the different aspects of the water sector.

However, the level of activity prompted by the private sector often overwhelms the response capacity (in terms of administration and oversight) available to the government. Increasing the ranks of government officials in charge of enforcing environmental and Water Code regulations is one of the main challenges facing the Chilean water sector in the next few years.

6. Acknowledgements

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7. References

1. Baladrón, F. “Estudio de la hidrodinámica del humedal Ciénagas del Name”. Tesis para optar al grado de Magíster en Ciencias de la Ingeniería, mención recursos y medio ambiente hídrico. Memoria para optar al título de ingeniero Civil. Universidad de Chile. (2011)
2. Bartosch, A. “Die Wasserversorgung in einer Metropolregion in Lateinamerika. Das Beispiel Santiago de Chile”. Diploma thesis, Jena. (2007)
3. Bauer, C.J. “Dams and Markets: Rivers and Electric Power in Chile”. Natural Resources Journal, 49 (3-4): 583-651. (2010)
4. Buschmann, A., and A. Fortt. “Efectos ambientales de la acuicultura intensiva y alternativas para un desarrollo sustentable”. Revista Ambiente y Desarrollo 21, no. 3: 58-64. (2005)
5. Cabello, F. C. “Antibiotics and aquaculture in Chile: Implications for human and animal health”. Rev. Med. Chile: 1001-1006. (2004)
6. Cenma. “Estudio para la implementación de medidas para el control de la contaminación hídrica: antecedentes de apoyo a la elaboración de la norma secundaria de calidad ambiental para la protección de las aguas del lago Llanquihue”. Realizado para Gobierno de Chile, Comisión Nacional del Medio Ambiente, X Región. (2006)
7. CEPAL. “La economía del cambio climático en Chile. Síntesis”. United Nations Publication. (2009)
8. CRH, Centro de Recursos Hidráulicos,

Universidad de Chile. "Crecidas Súbitas y corrientes de detritos ocurridos el 18 de Junio de 1991 en Antofagasta", Dirección General de Aguas, Ministerio de Obras Públicas. (1993)
9. de la Fuente, A., and Niño, Y. "Temporal and spatial features in the thermo-hydrodynamics of a shallow salty lagoon in northern Chile". Limnol. Oceanogr. 55: 279-288. (2010)
10. DOH–MOP. "Infraestructura Hidráulica del Chile 2020". Publicación Ministerio de Obras Públicas. (2010)
11. Falkenmark, M. "The massive water scarcity now threatening Africa – why isn't it being addressed?" Ambio 18:112-118. (1989)
12. FAO. "Visión general del sector acuícola nacional. Chile". National Aquaculture Sector Overview Fact Sheets. Texto de Norambuena, R. & González, L. In: Departamento de Pesca y Acuicultura de la FAO [en línea]. Roma. (2005) http://www.fao.org/fishery/countrysector/naso_chile/es
13. Ferreccio C., Gonzalez C., Milosavjlevic V., Marshall G., Sancha A., Smith A. "Luna cancer and arsenic concentrations in drinking water in Chile". Epidemiology 11:673-679. (2000)
14. Ferreccio C., Sancha A. "Arsenic exposure and its impact on health in Chile". J. Health Popul Nutr 24(2): 164-175. (2006)
15. Gaete, H., E. B Schmith, and A. Riveros. "Toxicidad crónica de las aguas receptoras de efluentes de industrias de celulosa sobre larvas de chironomus piger". Rev. Int. Contam. Ambient 21, N° 2, pp. 83-89. (2005)
16. Golder Associates S.A. "Informe sobre vulnerabilidades ante riesgo de aluviones en el sector Adit 71". Codelco Chile, División El Teniente. (2001)
17. Hauser, A. "Remociones en masa en Chile". Subdirección Nacional de(2000). Geología. Boletín N° 59. SERNAGEOMIN, Chile. (2000)
18. Hauser, A. "Los flujos aluvionales en Chile: causas, efectos y medidas de mitigación". Servicio Nacional de Geología y Minería. Subdirección Nacional de Geología. (2004)
19. Hiscock, K. M., M. O. Rivett and R. M. Davison. "Sustainable groundwater development". Geological Society, London, Special Publications 2002; Vol. 193; pp. 1-14 doi: 10.1144/GSL.SP.2002.193.01.01. (2002)
20. Houston, J. "Variability of precipitation in the Atacama Desert: its causes and hydrological impact". International Journal of Climatology 26(15): 2181-2198. (2006)
21. INE. "Población y sociedad, aspectos demográficos". Instituto Nacional de Estadísticas. ISBN: 978-956-7952-74-8. (2008)
22. Latin Focus. "Gross Domestic Product, by Sector. Chile 2000-2008". (2009) http://www.latin-focus.com/latinfocus/countries/chile/chlgdpsector.htm
23. Meruane, C. "El efecto del Viento Puelche en la hidrodinámica del lago Villarrica". Memoria para optar al título de Ingeniera Civil, Universidad de Chile. (2005)
24. MOP, Ministerio de Obras Públicas

Obras Públicas. "Una mirada de diez años". Unidad de Comunicaciones, Dirección de Arquitectura MOP. (2009)

25. Muñoz, A. "Desarrollo Cronológico del conflicto ambiental en los humedales del río Cruces, primer sitio Ramsar de Chile". Centro de Estudios Agrarios y Ambientales, Valdivia. (2005) http://www.ceachile.cl/Cruces/PDF/38.%20Cronologia%203.pdf
26. Palma, R., G. Jiménez and I. Alarcón. "Las energías renovables no convencionales en el mercado eléctrico chileno". Published by Comisión Nacional de Energía (CNE) and Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). (2009)
27. Parkinson, J., and O. Mark. "Urban stormwater management in developing countries". IWA publishing. (2005)
28. Peña, H., M. Luraschi and S. Valenzuela. Agua, desarrollo y políticas públicas: la experiencia de Chile. REGA, Vol. 1, No 2. pp. 25-50. (2004)
29. Perez J. y Vargas X. "Impacto del cambio climático en las crecidas de la quebrada San Ramón. Análisis de variables meteorológicas". Sociedad Chilena de Ingeniería Hidráulica, XIX Congreso Chileno de Hidráulica. (2009)
30. Rebufel V. "Chile: participación de la mujer en los fondos públicos de financiamiento en investigación científica y tecnológica y algunas propuestas de intervención". Editorial: FLACSO. ISBN: 978-956-205-239-9. (abril de 2009)
31. Rozas, C. "Análisis modal para el estudio de resonancia de ondas internas excitadas por el viento en el lago Villarrica". Tesis para optar al grado de Magíster en Ciencias de la Ingeniería, mención recursos y medio ambiente hídrico. Memoria para optar al título de ingeniero Civil. Universidad de Chile. (2011)
32. Sancha, A. M. and R. O´Ryan. "Managing hazardous pollutants in Chile: Arsenic Reviews of Environmental Contamination and Toxicology". Springer Ed. D. Whitacre. Vol. 196. pp. 123-144. (2008)
33. Salazar, C. and Soto, M. "Caracterización y monitoreo de sistemas lacustres en Chile". Dirección General de Aguas. (2006) http://www.aprchile.cl/Investigaciones/caracterizacion-y-monitoreo-de-sistemas-lacustres-en-chile.html
34. Silva, C. "Aplicabilidad de funciones de transferencia para proyección de efectos de cambio climático sobre caudales en la cuenca alta del río Loa". Memoria para optar al título de Ingeniera Civil. Escuela de Ingeniería, Universidad de Chile. (2010)
35. Vila, Irma, Marco A. Mendez, Sergio Scott, Pamela M. Morales, and Elie Poulin. "Threatened fishes of the world: Orestias ascotanensis Parenti, 1984 (Cyprinodontidae)". Environmental Biology of Fishes 80, No. 4: 491-492. (November, 2006)
36. Woelfl, S. "Consideraciones acerca de la eficiencia de normas secundarias para la protección de lagos de Chile". VII Congreso de la Sociedad Chilena de Limnología. Villarrica, Chile. (2010)


Tayrona National Natural Park, Colombia

The State of Water Resources in Colombia

An Overview

Mtra. Claudia Patricia Campuzano[1], Dr. Gabriel Roldán Pérez[2], Ing. Ernesto Guhl Nanneti[3], Mtro. José Manuel Sandoval Pedroza[4]

[1]Centro de Ciencia y Tecnología de Antioquia

[2]Universidad Católica de Oriente, Rionegro

[3]Instituto Quinaxi

[4]Ministerio de Ambiente, Vivienda y Desarrollo Territorial

Key words: availability, offer, demand, water quality, use of water, health, potable water, management, regulations.

1. Introduction

Until 1990 Colombia was the fourth country in the world with the highest water volume per unit surface area, only behind the Soviet Union, Canada and Brazil. According to experts, Colombia's average water yield was 60 liters per square kilometer, six times greater than the worldwide average and three times greater than that of South America. The prospect today is totally different. The decrease in water volume together with a fall in its quality, has reduced its availability. The main cause is indiscriminate logging, which directly affects aquatic and terrestrial ecosystems. In spite of the fact that our country is still privileged with respect to water resources, there are millions of Colombians without access to drinking water and basic sanitation. The present document intends to take a glimpse at the actual state of our country's hydrological resources. The information has been obtained from publications by important Colombian institutions that deal with water resources and the environment in general, including: The Environmental, Housing and Territorial Development Ministry (MAVDT - Ministerio de Ambiente, Vivienda y Desarrollo Territorial), The Institute of Hydrology, Meteorology and Environmental Studies (IDEAM - Instituto de Hidrología, Meteorología y Estudios Ambientales), The Autonomous Regional Corporations and Environmental Authorities; The National Comptroller's Office, as well as research institutions such as Universidad Católica de Oriente, Universidad del Valle, Instituto Quinaxi and Centro de Ciencia y Tecnología de Antioquia.

2. The Colombian Territory

Colombia is found in the northwestern corner of South America, within the latitudes of 12° 30' North and 4° 13' South. It has a continental extension of 1,141,748 km^2 and a continental platform and territorial seas of 928,660 km^2 (FIG. 1). It is the fourth largest country of the area, behind Brazil, Argentina and Peru. Colombia is the only South American country with a coast of 1,600 kilometers on the Caribbean Sea and 1,300 kilometers on the Pacific Ocean. As a result of its equatorial geographic position and its complex relief, it has a variety of climates and a mosaic of ecosystems. Our country includes one of the most complex and vulnerable ecosystems on Earth, containing

FIG. 1. Map of the Colombian Territory

10% of the world's plants and animals. The most important topographic feature of Colombia is the Andes mountain range, located in the central and western part of the country, running from north to south along most of its length. The Andes include three main parallel mountain ranges: the Cordillera Occidental, the Cordillera Central and the Cordillera Oriental. Along the Caribbean coast the isolated mountain mass known as Sierra Nevada de Santa María can be found. Simón Bolívar Peak, its highest elevation, is 5,775m.

The Cordillera Central includes the Huila (5,750 m) and Tolima (5,215 m) volcanoes. Nearly 240 km south of the Caribbean Sea, the Cordillera Central falls into swampy areas and tropical wet forest havens. The mountain peaks are permanently covered by snow, with a vegetation level reaching an altitude of up to 3,050 m. To the east of the Cordillera Oriental there are vast extensions of sparely populated and only partially explored torrid lowlands. The southern portion of this area is covered by rainforest of thick vegetation drained by the Caquetá river and other tributaries of the Amazon. The northern and largest part of the region is formed by enormous plains known as the Llanos Orientales crossed by the Meta river and other tributaries of the Orinoco. Between the mountains there are high plateaus, most of them with an elevation greater than 2,438 m, as well as fertile valleys drained by the main rivers of the country.

The most important Colombian river is the Magdalena and it flows north between the Cordillera Oriental and Cordillera Central, virtually crossing the entire country. Its length is approximately 1,538 kms and reaches the Caribbean close to the city of Barranquilla. Another important river and means of communication is the Cauca River; with a length of 1,350 kms, it flows north between the Cordillera Central and the Cordillera Occidental, joining the Magdalena nearly 320 kms before reaching the Caribbean. The Patía River to the west, runs across the Andes into the Pacific. There are many river mouths along the coasts, although they lack natural ports.

Considering the information above, five geographic regions can be recognized in Colombia (FIG. 2):

- The Andean region in the west, where most of the Colombian population lives. It consists of three mountain ranges (the Andes) that cross the country from north to south.

- The Caribbean region in the north, characterized by a warm climate, coasts and beaches. The coastal area includes land for agriculture and tourism.
- The Pacific area in the west, has a warm and humid climate and is covered by tropical forests and lush vegetation.
- The area of the Llanos Orientales in the southeast consists of vast extensions of flat and undulating land. It is rich in agriculture and ranching, and has many oilfields.
- The Amazon region in the country's southeast, is covered in enormous tropical forests.

Colombia has a population of 44,935,461 and is divided for political and administration purposes into 32 Departments and 1051 Municipalities. Seventy percent of the country's population lives in its most important cities which are: Bogotá, Medellín, Cali, Barranquilla, Cartagena, Santa Marta, Bucaramanga, Cúcuta, Pereira and Manizales.

3. Colombian Hydrological Resources –General Aspects

Because of its geographical position, varied topography and climate, Colombia has one of the world's greatest water supplies. Nevertheless, it is not equally distributed in the territory and is highly variable. Colombia's hydrological wealth is manifest in the extensive river network that covers its surface and its favorable groundwater storage, as well as the presence of lentic water bodies and enormous wetland extensions. The existence of high mountains, plentiful precipitation, extensive savannas and tropical rainforests, together with the strategic location of the national territory, determine the presence of

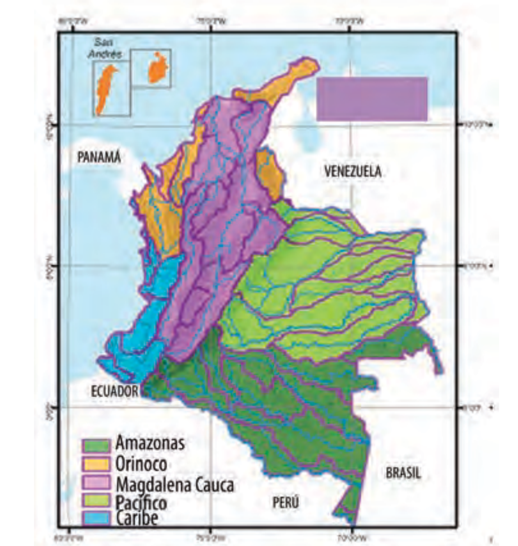
SOURCE: INSTITUTO GEOGRÁFICO AGUSTÍN CODAZZI – IGAC

FIG. 2. Geographic Regions of Colombia

ecosystems with high hydrologic potential and complex regulation systems. However, the use of this potential is restricted not only by the inadequate and inefficient use of water, but also by a series of human factors that affect the hydrologic cycle and above all, water quality.

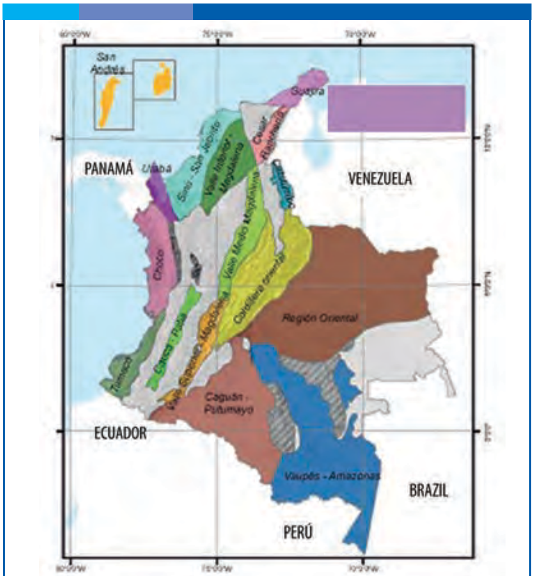
To perform an analysis of water resources in Colombia, the Ministry of Environment, Housing and Territorial Development has progressed in the definition of a National Policy for Integrated Water Resources Management, which recognizes the watershed as the regional planning unit Colombia, for which there was a zoning basin consists of three levels: first level corresponds to 5 major watershed areas, as presented in FIG. 3, the second level to forty-one watershed areas, and the third level to three hundred nine sub-basins.

Water indicators are analyzed to hydrological zones and subzones for the case of groundwater, the analysis is performed for hydrogeological zones in which the country was also divided, as shown in FIG. 4.



SOURCE: IDEAM, 2010.

FIG. 3. Hydrographic Zoning Colombia.



SOURCE: IDEAM, 2010.

FIG. 4. Hydrogeologic Zoning Colombia.

4. Hydrologic Balance

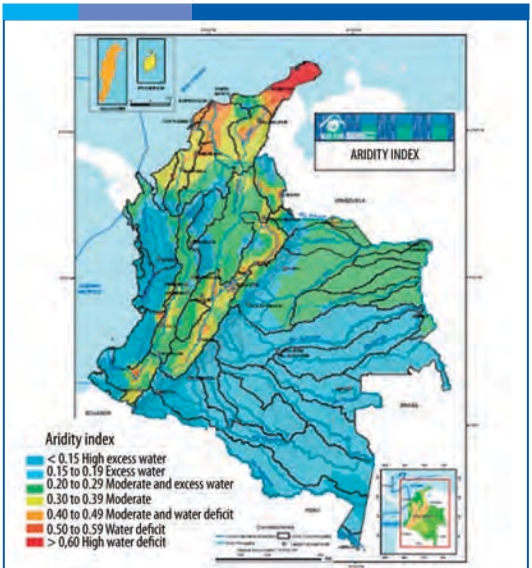
According to the IDEAM (2008), towards the end of the XXth century, Colombia occupied fourth place amongst the countries with the greatest water availability per capita; likewise, the UN report on worldwide development of hydrologic resources "Water for People, Water for Life", places Colombia in the 24th position amongst 203 countries. This indicates that Colombia is a world hydrologic power, in spite of its current problems of scarce supply and affectation of natural water sources. The situation is reflected in the following figures:

- Colombia has at least 737,000 bodies of water, including rivers, ravines, springs and lagoons (HIMAT, 1994).
- On average, 3,400 km^3 of water falls on Colombian territory annually, of which 1,100 km^3 evaporates and 2,300 km^3 drains. Supposing that a country has the capacity to store 40% of this supply, then Colombia should be able to have a surface water supply of 1,150 km^3 per year.
- The capacity to supply and provide water in our country has yet to reach this percentage.
- The most common water supply (supply modal) for Colombia amounts to about 1.910 km^3 per year, while in extreme events (drought year offer) does not exceed the 1,240 km^3 per year

Colombia's global hydrological balance, a measure of a country's hydrological potential, is presented in FIG. 5 an aridity index map built on a scale of 1:1,500,000 and based on the country's hydroclimatic regions.

According to estimates by IDEAM in the National Study on Water (Estudio Nacional del Agua -ENA) (2008), Colombia's water supply is over 2,000 km^3 per year, which corresponds to a yearly average of 57,000 m^3 per capita. However, if the decrease caused by reduced water quality and natural regulation processes is considered, the estimated average annual water available is only 34,000 m^3 per capita. In dry years this figure falls to a yearly average of 26,700 per capita, and is even less favorable or misleading if the heterogeneous distribution of water, population and economic resources are taken into account. Furthermore, according to calculations by IDEAM (2008), between the years 1985 and 2006, annual water available per capita fell from 60,000 m^3 to 40,000 m^3, at an approximate rate of 1,000 m^3 per year.

The study by IDEAM (2008) confirms that water distribution in the country is highly variable in space and time, in spite of Colombia's relatively favorable water resource supply and availability. In addition, the diversity in vegetation coverage, land, land usage, and the geological and hydrological characteristics of Colombian watersheds result in varied regulation capacities. As a result, while some areas have enormous runoff, such as the Pacific region where the rivers Dagua, Baudó, San Juan, Micay and Atrato are found, others have a very high runoff deficit such as the high and low Guajira areas, San Andrés and Providencia, the Cesar River basin and La Sabana in Bogotá, as shown in FIG. 6. In dry conditions, average water supply reduces between 50% and 65% (IDEAM, 2010). These variations in water supply are a cause of serious concern and even alarm in some municipalities and urban areas, because of poor planning for the use of water resources. The exploitation of water in urban aqueducts, supplied over 80% by small rivers, streams and brooks, in general lacks programs for watershed protection, systems for water regulation, storage, transportation and treatment, as well as the economic forecasts to carry them out.



SOURCE: IDEAM,2012

FIG. 5. Aridity Index Map in the Regions of Colombia

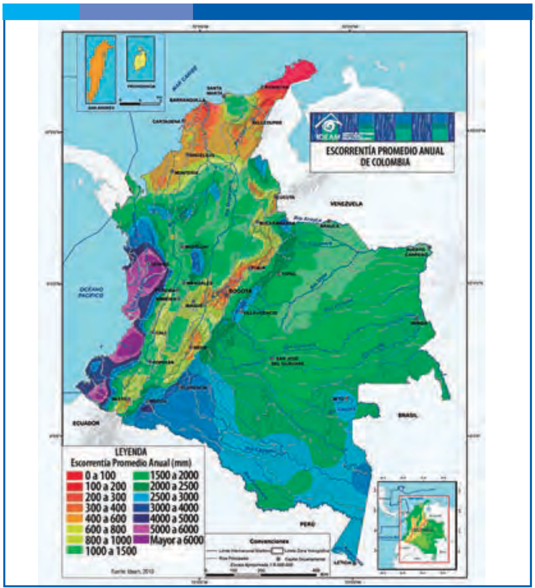
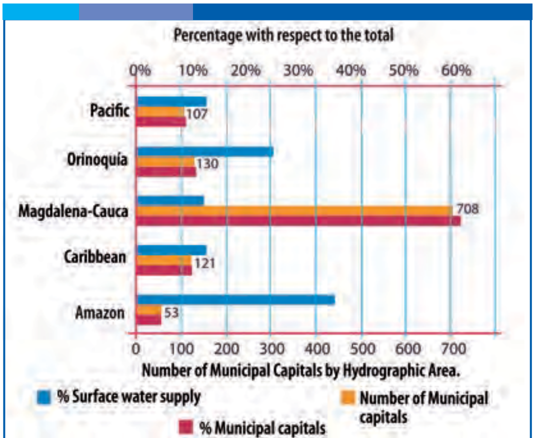


FIG. 6. Colombia's Multiannual Average Runoff Per Year

FIG. 7 shows the inverse relationship between average water supply and distribution of the municipalities in each of the regions of Colombia.



SOURCE: IDEAM, 2010

FIG. 7. Municipal Distribution and its Relation to the Average offer for Basin Area

5. Reservoirs and Wetlands

There are close to 1,600 bodies of water in Colombia, including lagoons, lakes and reservoirs. These contain important reserves of utilizable water, with a total volume of 26,300 million m³. Of the five great regions in Colombia (Caribbean, Pacific, Andean, Orinoco and Amazonia), the Caribbean region is of great importance due to the presence of 71% of the permanent or semipermanent wetlands, the most important of which is the Momposina Depression Complex, followed by the Mid-Magdalena River and the Atrato River. Most reservoirs in Colombia are found in the Magdalena River Basin, within the Andean region. 79% of the country's population is established here and the area is the center of a greater part of Colombia's economic activity (FIG. 8). As a consequence, these reservoirs are highly modified either by accelerated clogging and eutrophication or by native materials from the internal metabolism of the reservoir (Valderrama, 1985). To date, there are no reservoirs in the Sierra Nevada de Santa María, the Atrato basin, nor in Amazonia, and they are very scarce in the eastern side of the Cordillera Oriental (Márquez and Guillot, 1987).

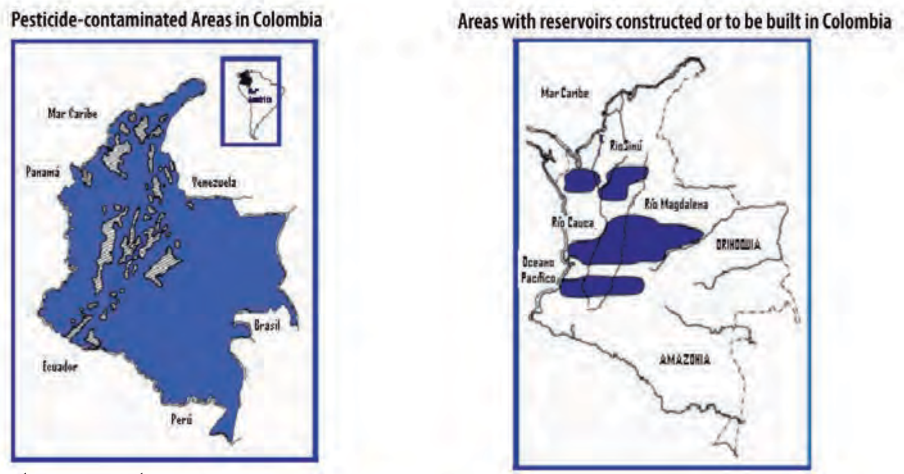
There are few limnology studies of tropical reservoirs in developing countries, including Colombia; only in the recent past have there been relatively detailed studies of the environmental effects of certain projects (Márquez and Guillot, 1987). Until 1987, the total area covered by reservoirs was 41,593 ha. This figure was supposed to triple towards the end of the 1990's reaching an approximate area of 125,111ha, however this goal was not attained due to social and economic reasons (Valderrama, 1985). According to Márquez and Guillot (1987), 16% of the reservoirs are found in warm climates (below 1,000 masl [meters above sea level]), 50% in temperate areas (between 1,000 and 2,000 masl) and 34% in cold climates (beyond 2.000 masl), which have a smaller risk of eutrophication due to the size of the watersheds and low population.

Environmental Problems in Reservoirs

The most serious environmental problems detected in Colombian reservoirs are related to corrosion, aquatic weed, fish mortality, domestic and industrial wastewater, rubbish and the reduction in flow volume from receiving sources. Table 1 shows how each of these factors affects Colombia's main reservoirs, while Table 2 shows their trophic status.

Corrosion.

Problems caused by corrosion have been reported in the generator equipment of several Colombian reservoirs. At El Peñol Reservoir (Antioquia), anoxic water loaded with dissolved iron (Fe++) and H_2S was causing serious corrosion in the engine rooms, thus forcing the respondent entity to install a mechanical aeration system to improve the chemical quality of water in the collector towers. Medina (1983) analyzes this problem thoroughly. In addition, abrasion caused by sediment-loaded water is common in tropical reservoirs due to the erosion of watersheds and heavy rains. The Prado Reservoir (Tolima) is chemically stratified and has a high production of sulphydric acid in a totally anoxic environment. The problem with corrosion is so serious that the high-resistance steel-covered headrace tunnels, began to crumble as a consequence of the sulphydric and iron metabolism of sulphuric and ferruginous bacteria.



SOURCE: ROLDÁN, G. Y E. RUÍZ, 2001

FIG. 8. Pesticide Contaminated Areas and Reservoirs in Colombia.

Table 1. Main Problems Present in Colombian Reservoirs.

Problems	Water Quality Deterioration	Presence of H_2S	Corrosion and/or Abrasion	Aquatic weed	Fish Mortality	Sedimentation	Pollution by garbage	Wastewater	Flow decrease
Reservoirs with information	15	15	16	15	15	18	14	14	16
Number of Reservoirs Affected	4	4	8	5	4	8	5	5	6
Percentage of Reservoirs affected	26.6	26.6	50.0	33.3	26.6	44.4	35.7	35.7	35.7

Table 2. Secchi Disc values and the Trophic Status of Colombian Reservoirs.

Reservoirs	Secchi Disc Values	Oligotrophic	Mesotrophic	Eutrophic	Hipertrophic
Betania (Magdalena)	1.02-2.89		■	■	
Betania (Yaguará)	1.02-2.89		■	■	
Calima	0.90-3.60		■		
La Esmeralda (Chivor)	0.09-1.30				
La fe	1.02-2.89	■			
Muña	0.25-0.90			■	
Neusa	0.60-2.40	■			
Peñol (Guatapé)	0.90-2.50			■	
Prado	0.30-2.00				■
Punchina	0.80-3.00	■			
Sisga	0.40-1.30	■			
Tominé	0.25-0.45	■			

Fish Mortality

Massive fish death has been reported in highly eutrophicated reservoirs, such as El Prado (Tolima). A possible cause is the strong fall in oxygen levels during the evening in this type of trophic reservoir (Márquez and Guillot, 2001). A wide variety of cyanophytic algae is also common and may be the cause of fish poisoning, although the most frequent cause of fish mortality seems to be nocturnal anoxia.

Sedimentation Problems

All reservoirs tend to accumulate sediment, however the velocity of clogging depends on the amount of sedimentary materials carried by the connecting rivers, the state of conservation of the surrounding watershed and rain intensity in the area. Due to the great sediment volume transported by tropical South American rivers, tropical reservoir design generally includes a dead storage capacity (extra capacity required to guarantee its useful life) of up to 40%. In the South American tropics, sediment dragging is high because of steep slopes that generally lack vegetation. The sediments in reservoirs also affect water's physical chemistry, especially light penetration, which in turn reduces the euphotic zone and therefore the photosynthetic capacity of the reservoir. In addition, certain kinds of sediments trap orthophosphates thus decreasing reservoir productivity.

The building costs of a reservoir are very high, therefore the importance of correctly estimating the sediments it might possibly receive. The lifespan of the Anchcayá

Reservoir (Valle), was calculated to be 50 years, yet it filled up with sediment in 10, thereby becoming an example of negligent technology (Allen 1972). The Betania Reservoir also shows early sediment accumulation; its lifespan has been calculated to be seven years less than planned which translates into an income reduction of 40 million US dollars per year, apart from social and economic damages in the region (Márquez and Guillot, 2001). The problem with sediment at El Guavio Reservoir (Cundinamarca), has been discussed by Roldán et al. (2000). They propose elevating the water inlet to reduce the sediments in the engine room and headrace tunnels. However, an elevation from for example 1,490 to 1,520 masl, would imply a fall in the project's profit of close to 1.0% and if elevated to a height of 1,540 masl, the loss would be close to 4.0%.

Domestic and Industrial Sewage

This is probably the most serious problem in the majority of Colombian reservoirs. Only a minimal number of municipalities treat domestic wastewater, dumping it directly into rivers and streams, and later ending up in reservoirs. This high nutrient input (mainly phosphorus and nitrogen) is the main source of eutrophication. The discharge of industrial wastewater, which also include heavy metals and toxic substances, is also frequent. A strip of aquatic microphytes (Eichhornia crassipes) in the tailwaters of the reservoir has been observed to act as an effective filter to remove a great portion of the pollutants and sediments from the currents that feed reservoirs. Until the 1980's, La Fe Reservoir (Antioquia), the main water supply for the city of Medellín, received wastewater from the neighboring municipality of El Retiro. Eutrophication became such a critical problem that a treatment plant for activated sludge was built, resulting in very significant signs of recovery. Guatapé, Porce II, La Fe, Río Grande (Antioquia) y Tominé (Cundinamarca) reservoirs are the most affected by wastewater.

Flow Reduction

This is an aspect that has hardly been studied in Colombia. Trujillo (1995), Hoyos (2002) and Cano (2004), who have investigated the criteria and methodologies to determine ecological flow, consider the importance of keeping a critical flow to avoid affecting the structure and composition of aquatic communities and to preserve the ecosystem's metabolism and the downriver hydrology of the reservoir. Most Colombian projects have not taken this into consideration and it is frequent to find dry watersheds several hundred meters downriver from reservoirs. They also have a brownish color due to turbinated water loaded with soluble iron that precipitates into the substrate once it has come into contact with oxygen in the air. This is associated to the anoxic bottoms found in most of Colombia's reservoirs. Watersheds also often have a reduced flow or are dry as a consequence of the diversion of water to build small municipal aqueducts.

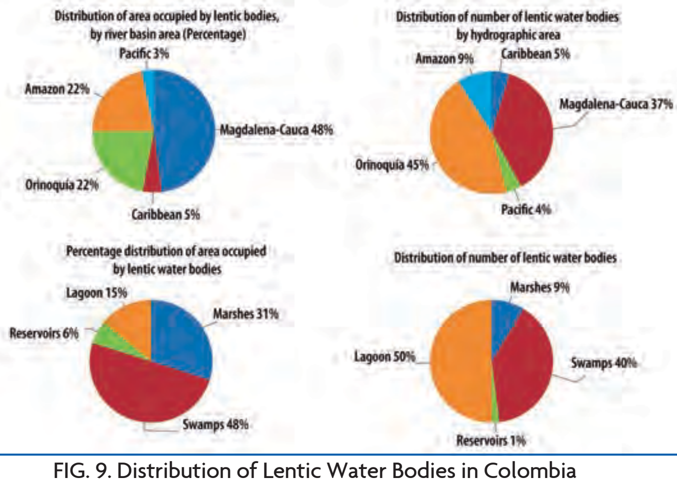
6. Other Resources (flood zones, swamps, glaciers, paramos)

The characteristics of the surface drainage network that covers the national territory determines the susceptibility to periodic flooding by alluvial rivers of the areas adjacent to natural riverbeds in low watersheds. These alluvial rivers are generally wide and have a permanent ebb tide as well as surges that are initially slow and long lasting. In general, the area susceptible to flooding in Colombia is greater than 102,000 km², of which less than 25% corresponds to the Magdalena-Cauca river basin. However this area is of considerable importance because it is home to a great portion of the population. The total area covered by swamps in Colombia is approximately 200 km², which represents close to 2% of the nation's continental surface. Sixty percent of these swamps are found in the departments of Amazonas, Guainía and Guaviare. Although it has not been possible to determine the real volume of water stored in swampy areas, it can be calculated by considering an average depth of 0.2 m (soil-water interface) and the fact that swamps contain an average of 95% water. Thus the total water volume of Colombian swamps can be estimated at nearly 11,500 million cubic meters.

In Colombia we have identified an area covered by lentic water bodies of approximately 832 ha. The percentage distribution described in FIG. 9.

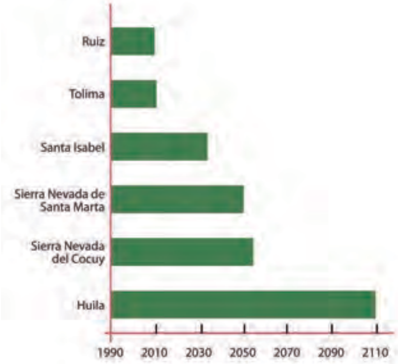
From historical records, including information on extreme levels in the different hydrological stations, evaluating the recurrence of these events occur. In the Table 3 shows the maximum levels for different return periods.

In total, there are 5,622,750 ha of marsh and other similar bodies of water, mainly in the departments of Bolívar and Magdalena. Lagoons represent close to 22,950 ha while floodable savannas cover a total surface of approximately 9,255,475 ha, and are found in the departments of Amazonas, Guainia and Guaviare. Floodable forests represent approximately 5,351,325 ha and are located in Orinoquía, Amazonia, Bajo Magdalena and to a lesser extent, in the Pacific area. Colombia currently has six glacier or snow-covered mountains: a) Sierra Nevada de Santa Marta (5,775 m), b) Nevado del Ruiz Volcano (Cordillera Central, 5,400 m), c) Nevado Santa Isabel Volcano (Cordillera Central, 5,110 m), d) Nevado del Tolima Volcano (Cordillera Central, 5,280 m), e) Nevado del Huila Volcano (Cordillera Central, 5,665 m), and f) Sierra Nevada El Cocuy (Cordillera Oriental, 5,490 m).



SOURCE: IDEAM,2010

FIG. 9. Distribution of Lentic Water Bodies in Colombia



SOURCE: ESTUDIO DE ALTA MONTAÑA COLOMBIANA, CONVENIO IDEAM – UNAL 1997

FIG. 10. Time estimated for Colombian Glacier Disappearance

Table 3. Maximum Levels Between Various Return Periods (Source: IDEAM, 2008)

Station	Maximum levels (cm)					
	2	5	10	20	50	100
Magdalena						
Pte. Santander	514	586	626	662	703	731
Purificación	701	748	775	799	827	846
Nariño	670	745	793	837	894	936
Pto. Salgar	516	552	582	617	670	718
Pto. Berrío	541	569	585	599	615	626
El Banco	839	887	908	922	937	946
Cauca						
La Balsa	334	393	429	462	502	531
Juanchito	536	610	651	685	725	752
Mediacanoa	574	616	635	649	664	673
La Victoria	670	751	796	834	878	908
Bolombolo	514	589	631	667	708	736
Pto. Valdivia	481	561	616	670	744	802
La Coquera	380	442	481	516	560	592
Las Varas	542	577	596	611	629	640
Sinú						
La Despensa	481	516	537	554	575	590
Mocarí	1,460	1,530	1,590	1,660	1,760	1,840
Montería	541	582	606	627	652	670

By 1997, eight small snow-covered mountains had lost their glaciers, and the "possible disappearance of Colombian glaciers" has been estimated according to research by IDEAM and the Universidad Nacional de Colombia. FIG.10. shows the approximate life left for each glacier based on the impressions made by ice towards the end of the neoglacial period (1850), aerial photographs throughout several decades, and recent field data. The analysis leads to the conclusion that Nevado del Ruiz and Tolima will be the next glaciers to go, while the Nevado del Huila will be the last. This information could vary if volcanic activity is reactivated for example, accelerating glacier melting.

According to information from the Primer Congreso Nacional de Páramos "Conservación con Equidad" in 2009, Colombia has 49% of the planet's paramos, with a total surface of approximately 1,932,987 hectares, i.e. 1.7% of the country's continental surface. They provide, amongst others, the water supply for human use and regional development of 70% of the colombian population, confirming the importance of the ecosystem as part of Colombia's natural heritage. This becomes even more significant in the light of the national goal "Objetivos del Milenio" to provide drinking water to an additional 7.7 million urban inhabitants.

7. Groundwater

According to IDEAM (ENA, 2000), hydrogeological studies have only been done on 15% of the total potential areas for exploitation of groundwater (414,375 km^2). The estimated reserves are 140.879 km^3, or the equivalent of 70 times the country's surface water. The same study mentions that Colombia draws groundwater from recent deposits as well as Tertiary and Cretaceous sedimentary units by means of wells 50 to 300 meters deep; however this information is only an estimate, as a global integrated inventory is lacking and is there no monitoring and follow up of groundwater collection. The distribution of retained provinces in Colombia, is presented in FIG. 11.

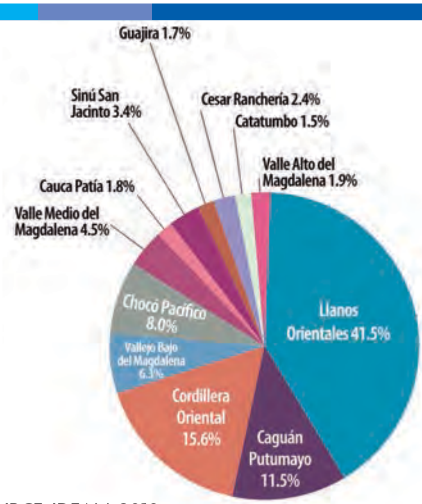
The Instituto Colombiano de Geología y Minería–Ingeominas, has developed the Atlas of Groundwater of Colombia (currently being validated), which states that underground waters can be found in 39% of Colombian territory. According to their productivity, the potential of aquifers can be classified as: very high, with a volume flow of ≥ 50 l/s (Valle del Río Cauca, Valle del Río Cesar, La Luna) or very low, with a water flow of ≤10 l/s (Sabana), as shown in FIG. 12.

8. Colombian Coastal Areas

55% of Colombia's territory corresponds to coastal areas, found mostly on the Pacific Ocean and the Caribbean Sea. Sea level on the Pacific is 5 meters while it is less than a meter on the Caribbean; the fluctuation can vary from 1 to 15 meters. These areas are not only part of the country's material riches, but also an important part of its environmental wealth.

Colombia's Caribbean coast extends to 65.800 km^2, covering approximately one fifth of the nation's territory. The productivity of its phytoplankton varies according to the physical, chemical and oceanographic conditions predominating at a specific time of year. This means that most productivity takes place during the period of upwelling.

Colombia's Pacific coast has an extension of 330,000 km^2 with an upwelling from a depth of 100 m. In addition, the mixed layer is nearly 150 m deep and characterized by turbulence and an almost uniform temperature and salinity. Here the phytoplankton productivity is greater than in the Caribbean and it is similarly determined by the predominant physical, chemical and oceanographic conditions at a specific time of year. Recently, the Pacific coast has suffered environmental changes associated to morphodynamic processes such as erosion, tsunamis, landslides and floods that have not only affected the local population, but infrastructure and ecosystems as well.



SOURCE: IDEAM, 2010

FIG. 11. Distribution of Groundwater Reserves in Colombia

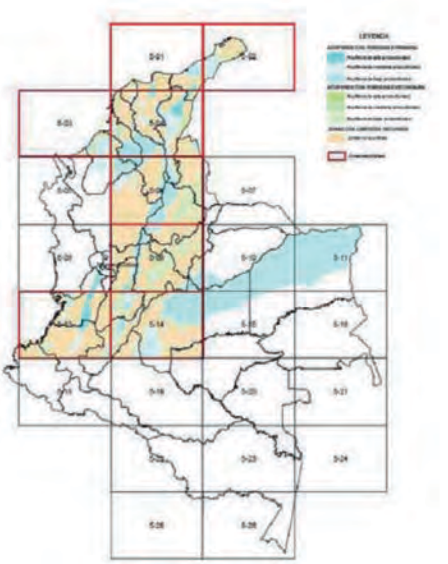


FIG. 12. Classification of Colombian Aquifers

Climatic variations such as "El Niño" Southern Oscillation and global warming have influenced coastal dynamics, increasing the rate of erosion of coasts and beaches. In addition, anthropic activities have also caused damage, as in the case of the Patía River delta. The river was diverted along its middle course by means of a 1.5 m canal to connect it to the Sanquianga marsh and the Pacific coast for economic reasons. This not only caused an impact on natural systems and settlements, but with time, the canal turned into the main riverbed with a width of 300 m and a river mouth displacement of 80 km. FIG. 13 shows a sample of this problem.

SOURCE: PHOTO BY NJ MARTÍNEZ, 1997

FIG. 13. Destruction of the Banks of the River Patía by the Widening of the River Bed

The "El Niño" Southern Oscillation produces an increase of Pacific Ocean water temperature of 2 to 3°C. It causes considerable changes in the ocean's dynamics, producing massive emigration of species plus the immigration of species that are uncommon in these waters.

It impacts not only planktonic and bentonic species like shrimp, but also species of fish and other animals with long migration routes such as marine turtles and whales.

Analysis by IDEAM show a slight tendency towards an increase in sea level at Tumaco and Buenaventura in the last three decades. The increase is in the order of 3 – 5cms in the past 25 years, and is in accordance with worldwide tendencies. Although the increase is slight, it must be handled carefully given the characteristics of the Colombian Pacific coast.

During 1995–1999, the Colombian Pacific suffered the effects associated to the Southern Oscillation warm and cold episodes known as "El Niño" and "la Niña" respectively. "El Niño" of 1997-1998 produced the greatest ocean surface temperature anomalies in the past 50 years, including major effects in Tumaco y Buenaventura. FIG. 14, shows an example of these effects in Tumaco where there was an average sea level increase of 30 cms.

SOURCE: PHOTO BY MP CUERVO

FIG. 14. Flooding Produced by El Niño 1997-1998.

9. Use of Water

According to IDEAM's National Water Study [Estudio Nacional de Agua (ENA)] 2005, the per capita water availability index classifies Colombia as 24th place in a list of 182 nations, thus no longer a hydrologic power. Each Colombian has 40,000 m^3 at their disposal per year; however, if conservation measures continue to be lacking, there could be negative effects on the country's sustainable development. Eventually, the problem could be such that by the year 2020, each Colombian could have a potential water volume of 1,890 m^3 per year.

The IDEAM's ENAs for the years 2005, 2008 and 2010 show the use of water by sector in the country. In 2004, agricultural water use was 59% of the total, while it increased to 61% by 2005, and then reduced to 55%, as shown in FIG. 15.

According to the ENA for 2005, Colombia lacks a system to obtain continuous and sectoral information on the use of water, and it has not measured the water consumed from surface, groundwater or desalination sources in the past. These measures would allow the assessment of the real pressures exerted by each sector on hydrologic resources in the future, emphasizing on the volume consumed more than the volume captured.

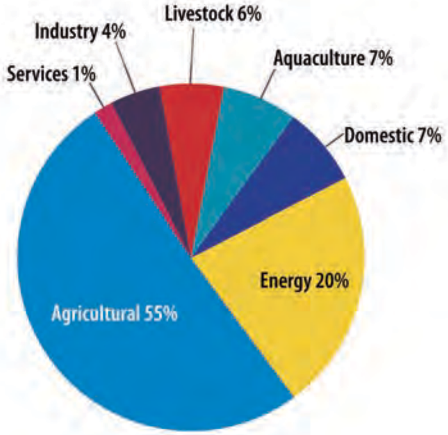


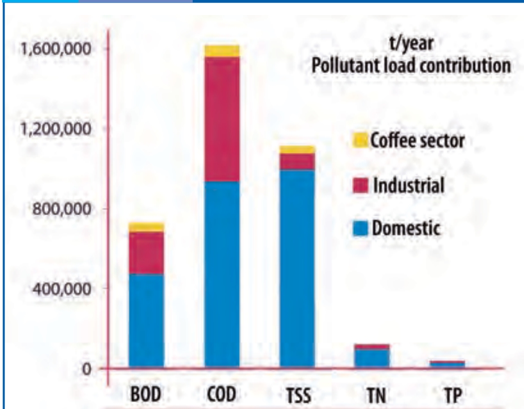
FIG. 15. Sectoral Participation in the Potential Demand for Water in Colombia

10. Quality of Water

The main factors altering water quality are domestic and industrial wastewater; wastewater from agriculture and ranching; stormwater; water from terrestrial, fluvial and oceanic transportation of dangerous compounds, as well as oil and its by-products; infrastructure work; water from mining processes; and solid wastes dumped into landfills or directly into bodies of water. FIG.16 shows the distribution of the main sectors of pollutant load contributions to the rivers.

The location of a highly dense population and production industries in Colombia's main Andean cities has caused pressure on the basins of the Magdalena and Cauca rivers. The tributaries of these rivers receive the greatest amounts of water quality-altering substances.

According to the Foundations for the Development of a National Plan for



BOD	COD	TSS	TN	TP
41.253	53.926	33.290		
213.273	625.906	84.714	19.868	2.209
474.857	938.372	996.825	96.852	27.152

SOURCE: IDEAM. 2010

FIG. 16. Pollutant loads Discharged into Water Systems by some Sectors in 2008

Wastewaters (Bases para la formulación de un Plan Nacional de Aguas Residuales) (Universidad de los Andes – Ministerio de Medio Ambiente, 2002), the flow of wastewater from Colombian cities is estimated to be close to 67 m^3/s, of which more than 15.3% corresponds to Bogotá, 13% to Antioquia, 9.87% to Valle del Cauca, while the remaining departments are below 5%. These proportions reflect the extent to which bodies of water are being affected and set a trend of impact on the regions.

Coastal areas mainly present pollution by domestic and industrial waste. Most domestic sewage is poured directly into coastal waters or rivers without treatment, largely into the Cauca and Bogotá rivers of the Magdalena watershed.

The highly organic effluents of the food industry, are also very often poured directly and without treatment into water currents, and together with domestic organic waste alter water resources. The cement industry modifies water by dumping suspended solids, while the petrochemical and carbochemical industries add complex chemical compounds to it. Additionally, given the vulnerability of oil duct and gas pipeline systems, the spilling of crude oil negatively modifies water quality and thus resident biota.

The manufacture sector, including the chemical industry, emits non-biodegradable compounds, as do the pharmaceutical, plastic and synthetic industries. An important amount of metals, hydrocarbons, carbon particles and sediments resulting from extraction and washing processes used in mining and oil industries, are added to water resources and then distributed to areas quite distant from the place they were emitted from.

All of these, together with other human activities such as territorial occupation and indiscriminate logging, play a role in water quality and affect hydrologic regulation in the country.

11. Vulnerability of Watersheds

According to the inventory of watersheds, Colombia has been divided into 12 zones, each with representative hydrologic characteristics, as shown in Table 4. Colombia has the privilege of sharing with Venezuela and Perú two of the longest and most plentiful rivers in the world, the Orinoco and the Amazon.

There is a clear relation between the most densely populated parts of the national territory and the most vulnerable watersheds.

The situation is evident in strategic watershed such as those of the rivers Magdalena, Cauca, Bogotá, Sogamoso, Sierra Nevada de Santa Marta, Sinú and Cesar. As to those on the border, governments have always been willing to subscribe bilateral action plans for their comprehensive development. Table 5 shows the degree of vulnerability

Table 4. Colombian Watershed Inventory (source: IDEAM, 2008)

Number	Areas	<10 Km^2	10 to 100 Km^2	100 to 1,000 Km^2	1,000 to 5,000 Km^2	5,000 to 10,000 Km^2	10,000 to 50,000 Km^2	50,000 to 100,000 Km^2	>100,000 Km^2
1	Pacífico y Atrato	91,500	3,900	153	26		4		
2	Bajo Magdalena Río Sinú	8,570	300	59	4				
3	Sierra Nevada de Santa Marta	19,100	170	47					
4	Baja y alta Guajira	3,750	300	45					
5	Alto Magdalena	8,400	320	72	16	2			
6	Medio Magdalena	20,700	1,420	142	17	4	1		
7	Alto Cauca	7,321	370	51	4				
8	Medio Cauca	6,420	177	89	6	2			
9	Cabeceras ríos Meta y Arauca	11,605	216	25	4				
10	Catatumbo	11,420	284	27	5				
11	Sabanas, ríos Meta y Arauca	5,525	510	170	34				
12	Ríos Guaviare Vichada y Amazonas	520,000	18,900	430	33	16	10	2	3 (2)
	Total	**714,311**	**26,967**	**1,310**	**149**	**24**	**15**	**2 (1)**	**5 (3)**

of 45 national watersheds. Because supplying water to the population is of upmost importance and considering the high vulnerability of water supply systems, the assessment of water availability tendencies has become a top priority. A large percentage of the country's aqueducts obtain water from small rivers, ravines and streams. This makes them highly vulnerable, especially in areas with serious problems of spatial and temporal distribution such as the departments of La Guajira, Cesar, Magdalena and Bolívar in the Caribbean region, and the departments of Huila, Tolima, Valle del Cauca, Cundinamarca, Boyacá, Santander del Norte, Santander and part of Cauca and Nariño in the Andean region.

12. Drinking Water and Basic Sanitation

Inadequate planning and land occupation have contributed to the deterioration of watersheds

Table 5. Vulnerability of the Natural Environment in 45 Watersheds (Source: IDEAM)

Code	Basin	Value	Natural Vulnerability
01	Alto Magdalena	4,4	
02	Sabana de Bogotá	4,0	
03	Medio Magdalena	4,0	
04	Río Sogamoso	3,6	
05	Bajo Magdalena	4,3	
06	Río Cesar	4,2	
07	Alto Cauca	4,2	
08	Medio Cauca	3.8	
09	Bajo Cauca	5.0	
10	Río Nechí	4,5	
11	S. N. S. Marta - occ.	4,4	
12	Río Tolo	6,4	
13	Río Atrato	6,2	
14	Sinú-Caribe	4,4	
15	S. N. S. Marta - norte	4,6	
16	Alta Guajira	2,0	
17	Baja Guajira	3,8	
18	Río Catatumbo	3,9	
19	San Andrés y Prov.	3,3	
20	Río Arauca	3,1	
21	Alta Meta	4,6	
22	Bajo Meta	3,1	
23	Río Vita	4,3	
24	Rio Tomo-Tuparro	4,5	
25	Río Vichada	5,1	
26	Alto Guaviare	5,6	
27	Medio Guaviare	6,2	
28	Bajo Guaviare	6,8	
29	Río Inírida	6,7	
30	Río Atabapo	5,5	
31	Río Guanía	6,6	
32	Río Vaupés	6,8	
33	Río Apaporis	6,8	
34	Alto Caquetá	5,1	
35	Bajo Caquetá	6,6	
36	Río Puré	6,9	
37	Río Putumayo	6,6	
38	Río Mira - Guiza	5,6	
39	Alto Patía	3,2	
40	Bajo Patía	5,4	
41	Río Saquianga - Patía Norte	6,3	
42	Río Micay	6,1	
43	Río Coyanero - Dagua	5,7	
44	Río San Juan	6,3	
45	Río Baudó y directos	6,8	

in Colombia, and consequently have affected the quantity and quality of available water. Aqueducts in 140 municipalities of 16 departments are vulnerable to water availability problems because in many cases the current water sources are ravines, with water that has become seasonal as a consequence of watershed deterioration.

Water sources in cities like Bucaramanga and Cúcuta, are unable to supply the minimal flow demanded through their aqueducts in dry seasons. The situation is even more critical in the municipalities of Popayán, Palmira, Buenaventura, Maicao, Santander de Quilichao and Pamplona where the deficit is between 15 y 30% of the water provided. Thus, with the exception of some of the large cities in the country, aqueduct systems are susceptible to supply scarcity; their design, operation and maintenance are vulnerable to excessive or reduced flow from supply sources, climate change, or pollution, that result from unsustainable use of natural resources and inadequate water management.

According to the Superintendencia de Servicios Públicos Domiciliarios (2006), the treatment plants used by the public sewage system of large cities (Bogotá, Medellín, Cali) have the capacity to treat only 32% of the wastewater poured into them. Even more worrying is the fact that cities like Barranquilla, Bucaramanga and Ibagué only treat of 17%, 26% and 11%, of their sewage respectively, while cities such as Cartagena, Cúcuta, Pereira, Manizales, Neiva, Pasto, Valledupar, Popayán, Palmira, Florencia, Sincelejo, Buenaventura, Piedecuesta, Tulúa, Armenia, Tunja, Rionegro, Cartago, Sogamoso and Girardot leave their sewage untreated. In other words, the backwardness in water treatment in Colombia is not only due to the lack of infrastructure for water treatment, but also to poor coverage by existent treatment plants. Only 354 (33%) municipalities in the country have treatment plants, of which 29% are not in operation. It has been estimated that out of the 159 m^3/sec of water captured nationally, the treated wastewater volume is close to 5 m^3/sec, or 3.1%.

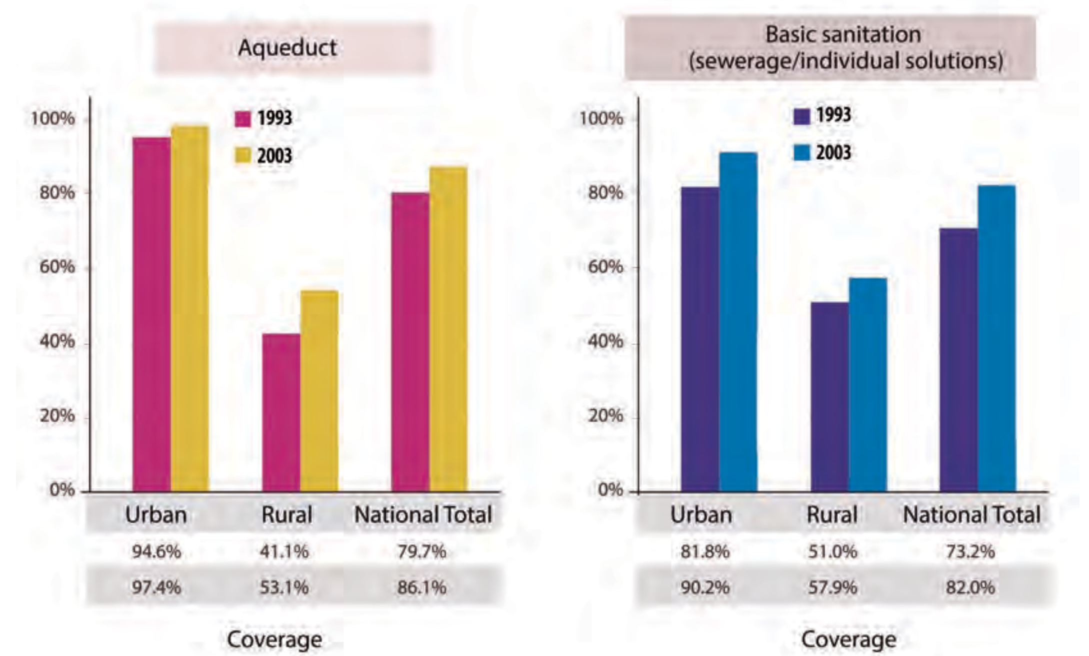
Due to deterioration of water quality and supplying watersheds; poor coverage, capacity and maintenance of water treatment plants; as well as the lack of control, follow up and monitoring of water quality, "17,736,687 Colombians did not receive water fit for human use during the first trimester of 2007".

It is important to mention the high vulnerability of municipal water conduits. During 2007 "nearly 200,000 inhabitants were affected by flooding (or collapsed sewage systems); almost 500,000 suffered from the suspension of aqueduct service as a consequence of avalanches, increase in river turbidity, and clogging or collapsing of collectors; while somewhat more than 20,000 had services suspended because of landslides that threatened the stability of a portion of the structure supplying the service". To date, the country not only lacks a plan to diminish this vulnerability but also the relevant research and inventories.

Studies on issues of access to basic services such as drinking water and sanitation, have shown that although there have been efforts to implement reform programs for these services and for broadening their coverage, especially since 2001, problems persist in relation to water quality and access in great areas of the country. The most recent data on the coverage of water conduits and sewage systems both in rural and urban zones are shown in FIG. 17.

In Colombian urban areas, the coverage of water services is good in general, although quality and continuity of supply are a problem. Large and middle sized cities have attained excellent and satisfactory services with respect to water quality, however smaller municipalities still have serious issues reaching the parameters established by current regulations. These problems are related to the low operational, financial and institutional capacity of small businesses, which result in poor infrastructure development, and the lack of resources for water purification and development of human capital. On the other hand, in rural areas the problems result from infrastructure coverage, as well as the lack of a continuous supply of high quality water. Important progress has been made between 2002 and 2006 in the number of municipalities that have wastewater treatment systems (Sistema para Tratar Aguas Residuales–STAR). In 2002 these were 218, and in 2006 they increased to 355. However, this last figure is still only 32.33% of the total number of municipalities in Colombia (including the Distrito Capital), meaning that the coverage is low overall.

It is also important to note that the percentage of municipalities with sewage treatment systems (STARs) in departments



SOURCE: MAVDT, PRESENTATION “WATER SUPPLY AND SEWAGE IN RURAL COMMUNITIES IN COLOMBIA”, DIRECCIÓN DE AGUA POTABLE, SANEAMIENTO BÁSICO Y AMBIENTAL, 2006

FIG. 17. Water Conduit and Sewage Systems in Colombia

including more than 100 municipalities, is lower than the national average (41.39%); Antioquia, Boyacá and Cundinamarca, have percentages of 31.2%, 20.83% and 38.79% respectively. This shows backwardness with respect to other regions in the country, but it most surely is a consequence of the size of the effort needed to provide the service to a greater number of towns. Table 6 shows the volume of flow treated by STARs in 2006.

Within this context, it is also important to note that although there is a great number of STARs installed or in the process of being installed, operation and maintenance has become an enormous challenge, as only 51% of them function well or fairly. This is caused partly by deficient knowledge on how to operate and maintain the systems, and the belief that wastewater-related problems are solved by building infrastructure alone, with only little importance given to maintenance and operation issues.

Economic sustainability of STARs is also an issue. In 77% of the cases there are no studies of impact on service fees, while in 80% the methodologies established by the Comisión de Regulación de Agua Potable y Saneamiento Básico (CRA) (Comission for Regulation of Potable Water and Basic Sanitation) have not been followed. The situation described implies that the sustainability of wastewater treatment plants is not guaranteed.

13. Water and Human Health

The lack of drinking water and basic sanitation in populations with poor living conditions is one of the main risk factors for contracting many illnesses. The absence of adequate disposal of feces (sewer systems, septic tanks, toilets) together with a lack of education promotes the spread of disease. The most serious consequence is persistent mortality and an increase in morbility caused by infectious diseases of water-borne nature in children in most of Colombia's municipalities. This is one of the highest costs of environmental breakdown in the country. According to information reported by Ernesto Sánchez-Triana, et. al., (2006) and taken from DANE (Departamento Administrativo Nacional de Estadísitca), 7.2% of all infant mortality is due to diarrheic diseases and the two-week prevalence in children below the age of 5 is 2.9%. Ninety percent of these cases are related to problems in the quality of water, sanitation and hygiene.

The Procuraduría General de la Nación states that 12.7 million Colombians still lack sewers and water pipes, in spite of the $117.5 billion (approximately 53 thousand million dollars) that the Colombian government has assigned to the sector in the past ten years. Of these, $7.2 billion (approximately 3 thousand million dollars) were assigned to address potable water issues.

In summary, it can said that in spite of resource investment from General Participation System (SGP), royalties and other sources, there continues to be high morbility and mortality due to water-borne bacterial diseases, especially chronic diarrhea. CONPES 3343 has established that the average cost to public health systems of "inadequate conditions for water supply, sanitation and hygiene, is $1.96 billions (approximately 890 million dollars)". In addition, living conditions and the geographical

Table 6. Municipal Wastewater Flow Treated

Department	Flow (m^3/s)	Population Coverage with wastewater treatment systems constructed	Flow treated (m^3/s)
Amazonas	0,11	50,00%	0,06
Antioquia	8,59	20,80%	1,79
Arauca	0,39	50,70%	0,20
Atlantico	3,42	26,10%	0,89
Bogota d.c.*	18,6	21,50%	4,00
Bolivar	3,22	8,90%	0,29
Boyaca	2,16	18,70%	0,40
Caldas	1,76	7,40%	0,13
Caqueta	0,67	0,00%	0,00
Casanare	0,46	26,30%	0,12
Cauca	2,01	48,80%	0,98
Cesar	1,54	60,00%	0,92
Choco	0,64	0,00%	0,00
Cordoba	2,11	28,60%	0,60
Cundinamarca	3,44	40,50%	1,39
Cuainia	0,06	100,00%	0,06
Guaviare	0,19	25,00%	0,05
Huila	1,48	5,40%	0,08
La Guajira	0,77	78,60%	0,61
Magdalena	2,06	23,10%	0,48
Meta	1,12	10,30%	0,12
Nariño	2,62	4,80%	0,13
Norte de Santander	2,16	15,00%	0,32
Putumayo	0,53	0,00%	0,00
Quindio	0,90	33,30%	0,30
Risaralda	1,51	0,00%	0,00
San Andrés y Providencia	0,12	0,00%	0,00
Santander	3,13	13,80%	0,43
Sucre	1,27	62,50%	0,79
Tolima	2,05	68,10%	1,40
Valle del Cauca	6,68	35,70%	2,38
Vaupes	0,04	33,30%	0,01
Vichada	0,14	0,00%	0,00
Colombia	**75,95**	**27,79%**	**18,93**

Source: MAVDT, Grupo Recurso Hídrico based on information from: (i) Plan Nacional de Manejo de Aguas Residuales Municipales – PMAR, published in June of 2004; (ii) Inventory by MAVDT in the framework of SINA, 2006 location of our territory in tropical areas, favor a high incidence of diseases transmitted by vectors, such as malaria.

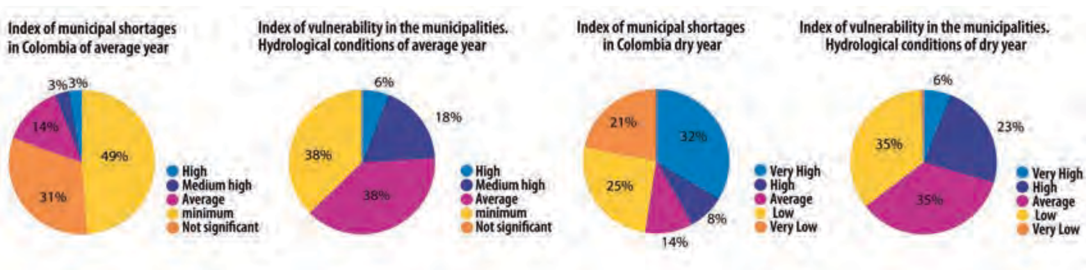
Finally, dengue fevers are today a serious problem to the health of the nation's population, especially in areas located at less than 1, 800 masl, home of the transmitter mosquito.

14. Supply and Demand Projections for 2015 and 2025

At the present moment, a good part of Colombia's municipalities and regions enjoy an adequate supply of water, in accordance with its plentiful availability in most parts of the country. Only a relatively low percentage has high scarcity rates, as can be seen in FIG. 18.
It is estimated that this could change quickly and significantly in the future, especially in more densely populated areas. In the coming years, water demand for human and economic use will not only increase, but the usable supply could also fall as a consequence of the current tendencies in deforestation and an almost complete lack of wastewater treatment.

In accordance with these conditions, the estimated supply for 2015 and 2025 was calculated by reducing the usable supply 2% annually. As to population, DANE (Departamento Administrativo Nacional de Estadística) used projections for 1995 to 2005, as well as population scenarios for 2015 and 2025 estimated within the DEAM-CIDSE agreement (Universidad del Valle, Cali), according to urban-rural differential growth methodology and using logistic formulae. For other sectors (industrial, commercial, livestock and agriculture), the projection considered an annual increase in demand of 3%, starting from the potential water demand for the year 2000. This figure was calculated after recognizing the need to consider at least three scenarios for GNP growth when making projections over more than 25 years.

These are: marked growth of around 6%; a recessive scenario of around 2%; and finally an average that comes close to the historical average GNP value for the past 20 years. This last scenario is in reality close to the growth average (2.6%) for 1980-1998, and can be



SOURCE: IDEAM, 2005

FIG. 18. Indices of Shortages and Vulnerability in Accordance with Water Availability in Colombia.

considered as a reference to project the most probable water demand. Nevertheless, a more precise econometric ratio could be established when more extensive series on water use and sectorial GNP growth are available.

Because water supply projections for 2015 and 2025 were calculated by reducing the supply 2% and increasing the demand 3% annually, the water scarcity index (pressure of demand over supply) tends to a rise slowly, thus anticipating that water availability will lead to a difficult situation with respect to its supply in the future. This indicates that the municipal scarcity index for 2015 and 2025 will increase considerably in municipalities found in the high water stress group. It also shows that the number of Colombians in this category will grow from 1.7 million in the year 2000, to 13.8 million in 2015 and could reach 17.5 million by 2025, or 30% of the total population projected for that year. The progression is similar for medium-high water stress and medium water stress groups, proving that the pressures of demand over supply are more and more significant and that 55% of the Colombian population would be found in these three categories (FIG. 19, Graphs A and B).

In the year 2000, 38 seats of municipal governments had a high scarcity index, while in 2015 the number is estimated to increase to 72, reaching a total of 102 in 2025. Forty eight seats of municipal governments had a medium-high scarcity index in 2000, while 101 are projected for 2015 and 138 for 2025. This corresponds to 13% of the total municipalities in the country, 70% of which are in the Andean area. The tendency is similar for medium water stress groups. According to projections, the population affected by a high and medium-high water scarcity could double, while the population with medium water stress tends to fall, because most municipality seats pass into more critical categories with high and medium-high water stress. (FIG. 19, Graphs C and D).

15. Water, Energy and Environmental Impact

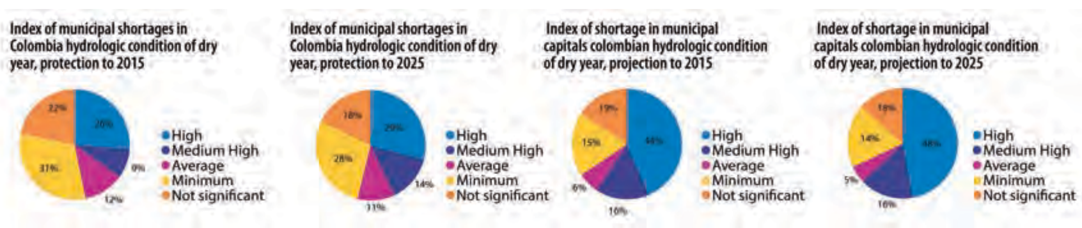
There are nearly 34 reservoirs with volumes over 1 Mm^3 in Colombia, close to 29 mid-sized reservoirs and many small ones. Eighty two percent of these are used to generate electricity. The total reservoir volume is nearly 10,724.5 Mm^3 with a total surface of 48 881 ha (Roldán, 1992; Márquez & Guillot, 2001; Roldán and Ramírez, 2008). Their areas vary between 56 and 16,000 ha, are found from 70 to 3,800 masl; have a generating capacity between 21 and 1,240 MW, and a residence time varying from 1.6 to 1.995 days. The energy they currently produce represents only 10% of Colombia's hydroelectric potential, therefore great activity is expected in the mid and long term in the field, with the ensuing ecologic, economic and social impacts that this sort of project entails. Table 7 shows the characteristics of the main 26 reservoirs in Colombia.

16. Governance of Water

At the moment, one of the greatest investments of the Colombian Plan de Desarrollo is in the purified water and basic sanitation sector, with the purpose of significantly increasing the population with access to these services. It is worthwhile to analyze administration methods for these new systems, so that they may guarantee the results expected from such a great national effort, and thus contribute to equality, health and the fight against poverty. In order to reach these objectives, the building of infrastructure, although essential, is not sufficient. Economic reforms based on liberalization and decentralization, considered necessary to change the role of the state from a provider of public services to a regulator and facilitator.

They deemed convenient to give the private sector a more prominent role in the provision of water services, for the purpose of mending governance difficulties, adducing improved efficiency and the possibility of allowing access to new financial and technological sources for service improvement and broadening. In the first part of the 1990's, a wave of privatization, especially in water services, rapidly extended throughout the world, increasing participation of private operators from almost none in 1990 to 2,350 in 1993. Latin American countries chose to follow along these lines to a greater or lesser extent.

An evaluation of the privatization of water services presents contradictory results, although they are overall unsatisfactory. Privatization policies show benefits in urban areas of high to medium income, but have failed with lower income consumers. They have produced complex situations and even law and order disturbances in cases such as Cochabamba and El Alto in Bolivia, and the early termination of contracts due to very high costs and lack of efficiency as in the water treatment plant in Bogotá.



SOURCE: IDEAM,2005

FIG. 19. Water Scarcity Rate Projections in Colombia for 2015 and 2025

Table 7. The Most Important Characteristics of Colombian Reservoirs and their Capacity for Energy Production (Taken from: Roldán and Ramírez, 2008).

Reservoirs	Year	Main River	Z max (m)	Area / ha	Peri-meter (km)	Max. Cota (Max. Level)	Installed capacity (MW)	Total Useful Volume (Mm^3)	Flow (m^3/s) (m^3/s)	Resi-dence (días)	Pur-pose
Alto Anchicayá (Valle)	1974	Anchicayá	132	140	25	640	345	30	99	3.5	Energy
Bajo Anchicayá (Valle)	1959	Anchicayá	53	-	-	195	64	15	110	1.6	Energy

Betania (Huila)	1987	Magdalena	91	7400	-	561	510	1020	786	15.0	Energy and Control
Calima (Valle)	1967	Calima	98	1980	-	1400	120	438	76	66.6	Energy
Chuza (Cundinamarca)	1983	Chingaza	27	98	-	3850	-	225	13	200.2	Aqueduct
Guatapé (Antioquia)	1973	Nare	60	6365	419	1887	560	1169	88	153.7	Energy
Guájaro (Atlántico)	1964	C. del Dique	4.0	16000	-	60	-	238	-	-	Risk
Guavio (Cundinamarca)	1993	Guavio	232	1530	15	1630	1000	1140	72	183.2	Energy
La Esmeralda (Boyacá)	1976	Bata	226	1260	83	1277	1000	634	160	45.8	Energy
La Fe (Antioquia)	1972	Las Palmas	30	1426	8	2155	16	12	8	17.3	Aqueduct and energy
Miel 1 (Celdas)	2002	La Miel	188	2050	-	445	400	565	-	-	Energy
Miraflores (Antioquia)	1965	Tenche	63	800	47	2062	-	140	18	90.8	Energy
Muña (Cundinamarca)	1944	Bogotá	5	933	-	2580	36	10	1	115.7	Energy
Neusa (Cundinamarca)	1951	Neusa	11	950	-	2997	190	106	2	613.2	Aqueduct
Playas (Antioquia)	1987	Guatapé	65	702	-	980	200	47	126	4.3	Energy
Prado (Tolima)	1973	Prado	90	3900	-	370	55	500	115	50.3	Energy
Porce II (Antioquia)	2001	Porce	118	890	-	922	392	82	201	4.7	Energy
Punchiná (Antioquia)	1984	Guatapé	65	340	17	775	1240	50	142	4.1	Energy
Río Grande (Antioquia)	1989	Río Grande	59	1100	-	-	325	100	50	23.1	Energy and Aqueduct
Río Mayo (Nariño)	1969	Mayo	16	56	-	1500	21	450	11	473.3	Energy
Salvajina (Cauca)	1985	Cauca	148	2031	102	1155	270	753	350	24.9	Energy and Control
San Lorenzo (Antioquia)	1987	Nare	57	1070	42	1250	170	180	40	52.1	Energy
Sisga (Cundinamarca)	1951	-	15	676	-	2780	-	101	3	389.5	Aqueduct
Tominé (Cundinamarca)	1962	Tominé	19	3690	-	2605	-	690	4	1995.0	Aqueduct
Troneras (Antioquia)	1962	Guadalupe	37	465	35	1775	36	36	26	16.0	Energy
Urrá I (Córdoba)	2000	Sinú	73	7400	-	128	340	1200	700	19.8	Energy and Control

Privatization has proved useful to improve distribution systems and reduce non revenue water, but has failed with respect to water distribution equity, broadening of services, wastewater treatment, and conservation of water-producing ecosystems. The contribution of the private sector to providing drinking water and basic sanitation services efficiently, may be convenient and significant, but the role of the State must be clear and should be exercised with efficacy and transparency. As a result of the experiences described above, a tendency to reverse the wave of privatization of potable water services can be noted from the middle of the present decade. Multinational water service companies are moving away from developing countries and concentrating on developed ones, as they offer less political and financial risks. Although the debate on the provision of services by the state or the private sector is still ongoing, it is important to identify new roles for the stakeholders thus widening the range of providers for these services.

International experiences and from civil organizations have led to the conclusion that governments and multilateral entities have not given due importance to other forms of water management. These alternatives could help overcome the debate between public and private management, and explore more open ways of organization such as public-private associations and consumer organizations. The experience with such organizations has proved to be effective in various countries, especially in the handling of rural aqueducts and small populations where they have very effectively contributed to equal access to water resources, improvement of living conditions and poverty reduction

17. Water Policies and Legislation in Colombia

Concern for water resources in Colombia coincides with the worldwide relevance given to environmental issues that began to be evident in conferences, symposia, and meetings. Considering the definition of "environment" as everything that surrounds living things and allows them to develop, water becomes a vital element for life. In this respect, the inefficient use of water and the breakdown of its quality become one of the main obstacles in the attainment of environmental, economic and social sustainability. Until recently, water in this country was believed to be an everlasting element for development, given its abundance and its associated biodiversity; it was not possible to recognize the consequences of man's ancestral relationship with nature in our culture. The presence of water became a determining element for rural and urban human settlements, although no importance was given to its protection and conservation. Eventually Colombia began to take part in the global concern for water and started to plan for more integral and globalized management along international guidelines.

In the Stockholm Summit of 1972, the Brutland report defined the relevant and definitive aspects for sustainable development under the ethics of conservation. Later, the Río Summit reasserted unique principals for administration of natural resources, considering the principles of global action and management, plus social, economic and political development.
Taking up the regulations that emerged

from these world summits again, Colombia created the Ministry for the Environment in 1993 by means of Law 99, which assumed some of the functions previously performed by organizations such as INDERENA and the Ministry of Health, amongst others. This Ministry defined the policy guidelines for various environmental aspects, some of which are mentioned below:

- Policy Guidelines for the Comprehensive Management of Water (Lineamientos de Política para el Manejo Integral del Agua), 1995.
- Foundations for a National Policy on Population and the Environment (Bases para una Política Nacional de Población y Medio Ambiente), 1998.
- Strategies for a National System of Natural Protected Areas (Estrategias para un Sistema Nacional de Áreas Naturales Protegidas).
- Guidelines for a National Policy on Territorial Environmental Planning (Lineamientos para la Política Nacional de Ordenamiento Ambiental del Territorio), 1998.
- National Environmental Policy for Sustainable Development of Colombian Oceans, Coastal and Island Areas (Política Nacional Ambiental para el Desarrollo Sostenible de los Espacios Oceánicos y las Zonas Costeras e Insulares de Colombia), 2000.
- National Policy for Colombian Internal Wetlands (Política Nacional para Humedales Interiores de Colombia), 1994.
- National Policy for Environmental Education (Política Nacional de Educación Ambiental), 2002.

In 2004, the government set forth guidelines for a new Water Law, an effort which in the end was unsuccessful. The objective was to: "promote water culture to ensure its efficient and sustainable use; establish the main procedures to regulate its exploitation and use; guarantee the population access to water in sufficient quantity and quality; develop organizations for administration and control in order to protect water resources and to give water its proper value so that it is used and disposed of correctly".

Thus began the construction of an integrative vision around planning, management, control, assessment and sensitization to water resources. After two years (2008-2009) of studies and consultations, a diagnosis of the hydrologic situation and its management, more than 14 multisector workshops, and the approval from the National Environmental Council in 2009, a diagnosis of the condition of water resources was prepared. It lead to the "National Water Policy" issued by the Ministry for the Environment, Housing and Territorial Development in 2010. It provides the framework, principles, objectives, instruments and strategies for the administration and planning of water resources, and also directs the water administration tasks of Regional Environmental Authorities (Regional Autonomous Corporations, amongst others).

The National Hydrologic Policy includes 6 specific objectives referring to supply, demand, quality, risks, management and institutional operation, each of which includes strategies (19), goals and indicators. The guidelines for strategic action will be developed in detail in the National Hydrologic Plan, according to regional characteristics and idiosyncrasies, but aiming at the attainment of the national objectives and goals defined in the present Policy. In addition to the Hydrologic Plan, a CONAPES will be formulated together with the National Planning Department to determine the sectoral actions that will promote national integral management of hydrologic resources.

The following is a list of the corresponding regulatory framework in Colombia. As has been mentioned beforehand, the various problems that are still present with respect to water matters, are not due to lack of legislation, but to the diversity of norms, lack of political will to apply regulations adequately, in addition to a lack of environmental education.

a. Water resources in general

- Law 23 of 1973, "By means of which extraordinary faculties are given to the President of the Republic to issue the Code for Natural Resources and Environmental Protection and to announce other orders".
- Act 2811 of 1974, "National Code for Renewable Natural Resources and Environmental Protection".
- Act 1449 of 1977, "By means of which the following are partially regulated [Paragraph 1, Number 5, Section 56 of Law 135 of 1961] and [Executive Decree No. 2811 of 1974]". Partial revocation Law 79 of 1986, Law 373 of 1997 and Act 1791 of 1996.
- Act 1541 of 1978, "By means of which Part III, Book II of Act 2811 of 1974 'of non-maritime waters' is regulated".
- Law 9 of 1979, "By means of which sanitary measures are enacted".
- Act 1594 of 1984, "By means of which Section I of Law 9 of 1979 is regulated, as well as Chapter II, Section II, Part II, Book I of Act 2811 of 1974 on the use of water and liquid wastes".
- Political Constitution of Colombia, Sections 78, 79, 80, 365, 366, 367, 368, 369 and 370.
- Law 99 of 1993, "By means of which the MINISTRY OF THE ENVIRONMENT is created, the Public Sector in charge of management and conservation of the environment and natural resources is reorganized, the National Environmental System (SINA - Sistema Nacional Ambiental) is organized, and other dispositions are enacted".
- Law 373 of 1997, "By which the program for efficient water saving and use is established".
- Law 1220 of 2005 "By which Section VIII of Law 99 of 1993 on environmental licenses is regulated".

b. Bodies of water and hydrographic basins

- Law 161 of 1994 "By which the Corporación Autónoma Regional del Río Grande de la Magdalena, is organized, its sources of financing are determined and other provisions are enacted".
- Law 357 of 1997, "By which the 'Convention on Wetlands of International Importance Especially as Waterfowl Habitats', subscribed in Ramsar on February 2, 1971, is approved".
- Act 1604 of 2002, "By which Paragraph 3, Section 33, Law 99 of 1993 is regulated".
- Act 1729 of 2002, "By which Part XIII, Section II, Chapter III of Decree-Law 2811 of 1974 on hydrographic basins is regulated, Number 12, Section 5, Law 99 of 1993 is partially regulated and other regulations are enacted".
- Resolution 769 of 2002, "By which provisions are enacted to contribute to the

protection, conservation and sustainability of paramos". Modified by Resolution 140 of 2003.

- Resolution 839 of 2003, "By which the reference terms to develop the 'Study on the Current State of Paramos and the 'Plan for Environmental Management of Paramos are established". Modified by Resolution 1128 of 2006.
- Resolution IDEAM 104 of 2003, "By which the criteria and parameters for the classification and prioritization of hydrographic basins are established".
- Resolution 196 of 2006, "By which the technical guide for the development of management plans for wetlands in Colombia is adopted".
- Act 1480 of 2007, "By which national planning and intervention of some hydrographic basins are prioritized and other provisions are enacted".

c. Management instruments

- Act 1600 of 1994, "By which SINA is partially regulated in relation to the Sistemas Nacionales de Investigación Ambiental y de Información Ambiental".
- Act 1933 of 1994, "By which Section 45 of Law 99 of 1993 is regulated".
- Act 3100 of 2003, "By which fees for the direct use of water as a receptor of specific discharge are regulated and other decisions are taken".
- Act 155 of 2004, "By which tax for the use of water is established".
- Act 3440 of 2004, "By which Act 3100 of 2003 is modified and other provisions are adopted".
- Act 4742 of 2005. "By which Section 12 of Act 155 of 2004 is modified and Section 43 of Law 99 of 1993 on taxation for use of water is regulated".
- Resolution 865 of 2004, "By which the methodology to calculate surface water scarcity index is adopted".
- Resolution 872 of 2006, "By which the methodology to calculate groundwater scarcity index is determined as referred to in Act 155 of 2004 and other provisions are adopted".
- Act 1900 of 2006, "By which the Paragraph in Section 43 of Law 99 of 1993 is regulated and other provisions are enacted".
- Act 2570 of 2006, "By which Act 1600 of 1994 is added to and other provisions are enacted".
- Act 1323 of 2007, "By which the Information System for Water Resources (SIRH -Sistema de Información del Recurso Hídrico), is created".
- Act 1324 de 2007, "By which the Water Resources Consumer Register is created and other provisions are enacted".

d. Potable water and sanitation

- Law 142 of 1994, "By which the residential public service system is established and other provisions are enacted".
- Act 3102 of 1997, "By which Section 15 of Law 373 of 1997 is regulated in relation to the installation of water use reduction equipment, systems and implements".
- Resolution 1096 of 2000, "By which the Technical Regulations for Potable Water and Basic Sanitation Sector (Reglamento Técnico para el sector de Agua Potable y Saneamiento Básico – RAS) is adopted". Modified by Resolution 668 of 2002 and 1459 of 2005.
- Resolution CRA 150 of 2001, "By which basic and maximal consumption is determined in

conformity with Law 373 of 1997".

- Resolution CRA 287 of 2004, "By which tariff methodology to regulate the calculation of costs for waterworks and sewage is determined".
- Resolution 1443 of 2004, "By which Section 12 of Act 3100 of 2003, on Plans for Sanitation and Management of Water Discharge (Planes de Saneamiento y Manejo de Vertimientos – PSMV) is established, and other provisions are adopted". Modified by Resolution 2145 of 2005.
- Act 1575 of 2007, "By which the protection and control system for water quality for human use is established".
- Resolution 2115 of 2007, "By which the characteristics, basic means and frequency for the control and surveillance system for water quality for human use are fixed".
- Act 3200 of 2008, "By which the norms for Departmental Planes for the Business Management of Water and Sewage Services and other provisions are enacted".
- Resolution 811 of 2008, "For the definition of guidelines to be followed by sanitation authorities and service providers to coordinately define, within their area of influence, sampling sites for the control and monitoring of water quality for human use in the distribution network".

e. Contamination and discharge

- Act 1875 of 1979, "By which norms for prevention of marine contamination and other provisions are issued".
- Act 1594 of 1984, "By which Section I, Law 9 of 1979 is regulated, as well as Chapter II, Section II Part II, Book I of Act 2811 of 1974 on the use of water and liquid wastes.
- Law 56 of 1987, for the approval of the "Agreement Concerning Protection and Development of the Marine Environment in the Wider Caribbean Region" and the "Protocol Concerning Cooperation to Combat Oil Spills in the Wider Caribbean Region", signed in Cartagena de Indias, March 24, 1983.
- Law 55 of 1989, for the approval of the International Agreement on Civil Responsibility for Damage Caused by Oil Polluted Marine Waters of 1969 and its 1976 protocol.
- Act 2190 of 1995, December 14, 1995. "By which the 'National Contingency Plan Against Spillage of Oil, Derivatives and other Harmful Substances into Marine, River and Lake Water' is developed".

f. Ocean water and continental platform

- Law 10 of 1978, "By which regulations on territorial oceans, exclusive economic zones, continental platforms and other provisions are enacted".
- Act 1875 of 1979, "By which regulations on the prevention pollution of marine environments and other provisions are enacted".
- Act 1436 of 1984, "By which Section 9 of Law 10 of 1978 is partially regulated".
- Law 611 of 2000, "By which regulations for the sustainable development of wild animal and aquatic species are enacted".

g. International treaties and agreements

- Law 119 of 1961, "Convention on Fishing and Conservation of the Living Resources of the High Seas".
- Law 408 of 1997, "By which the Agreement on International Hydrographic Organization

IHO", subscribed on May 3. 1967 in Monaco is approved.
- Law 74 of 1979. "By which the 'Amazonian Cooperation Treaty', signed on June 3, 1978 in Brasilia is approved".

18. Threats to Water in Colombia

In his article "Water in the Sustainable Development of Colombia. What Do We Want Water For?", Dr. Guhl mentions the importance of water as a strategic resource for development. He also underlines the importance of understanding that water is a limited resource that could no longer be renewable if it is poorly managed. He proposes two areas to be considered for the sustainable use of water: conservation of the hydrologic supply, i.e. amount of available water; and quality preservation to ensure its safe use from the perspective of human health and ecosystems. With respect to the first of these considerations, the adequate management of watersheds and water-producing environments such as paramos, is essential to avoid damaging events such as lack of flow regulation and erosion caused by the loss of forest coverage. In other words, conservation must be a determinant priority if we wish to keep our hydrologic wealth. For this reason permission from the environmental authorities to allow agriculture expansion into paramos for intensive potato culture, is inexplicable.

Looking into the future, it can be argued that the vast national supply of water does not coincide with the areas of major human activity and settlement where the demand is greatest. According to official data a water deficit in the "developed" parts of the country can be anticipated, and could produce a high risk of scarcity in its aqueducts. This would imply a true sanitary and economic emergency, that must be avoided through planning and decisive action.

The paradoxical situation of scarcity in the midst of abundance is a mistaken reading of reality. On the one hand, the data refer to the amount of water without considering quality, which is the greatest limitation to its use; and on the other they refer to current supply sources which often are small ravines with acceptable water quality. While these are highly susceptible to flow reduction due to climate, larger rivers are not used to provide aqueducts for reasons such as cost and contamination. A clear example of this paradox is Barrancabermeja, a municipality with a high scarcity of water in spite of being located on the Magdalena River.

As to water quality, it is essential to modify the ways we discharge domestic, industrial and agricultural waste untreated into rivers, full of organic and chemical pollutants and above all pathogens in such high quantities that make the use of these waters impossible.

The common practice of moving polluted waters downriver does not recognize the universally accepted principal "the polluter should pay the price", as it transfers environmental impact and cost to other areas. Although, as mentioned above, only 32.33% of Colombian municipalities treat their wastewater, just treating water is not enough. The level of water treatment should depend on how it will be put to use again after being poured into currents. In an autistic and selfish attitude based on the erroneous supposition that water is an endless resource, we use rivers as the "garbage dumps" of towns and cities, assuming that the river will "take away" the wastes and recover later. However, we are not recognizing the limit to rivers' self-purification and ignore what occurs to inhabitants further down its flow.

In the short term, there is a risk that water contamination, especially by domestic wastewater, will make the main rivers in Andean and Caribbean areas unusable. This situation is a cause of a national public health concern and regional inequality with respect to water quality and the costs of its purification.

As to planning and water management, it may be said that the country has lacked a comprehensive vision of water and its cycle, resulting in segmented and sectoral management, erroneously considering that the entirety of water resources are available for each and every use. The lack of knowledge of the water supply and its seasonal variations has led to unrealistic concessions for its use, which are frequently given as a percentage of available flow that is very difficult to identify and impossible to control.

19. Potential uses and Administration Mechanisms for Water in Colombia

Dr. Guhl also mentions in his article that water has traditionally been considered a resource of public domain in many countries including Colombia, due to its importance as a basic element for life. As has been explained previously, this idea implies that water is not just any exchangeable good, and that the state should own and control it, not private citizens. This has given rise to the regulation of its uses and potential services. Currently, the legal instrument for this is the concession of a certain amount of water or the percentage of a flow for the purpose of developing an activity linked to the land where the activity occurs.

In several countries and regions where water scarcity is temporary or permanent, for natural reasons or because the demand is too great for the available supply, allocation of water resources has been made more efficient by creating a market for water rights. As a consequence, these rights can be bought or leased allowing water to be used in accordance with the needs of people or production. In Spain, where very important areas lack water, this mechanism has been used to allocate a scarce resource in the best possible way. However the market for water rights is regulated to conform to public interest criteria by limiting the freedom of agreement between parties and exercising administrative controls. Thus only water rights for the "use of greater rank", according to legal prioritization, can be negotiated to avoid speculation or the creation of monopolies. The water market, limited by public interest criteria through adequate regulation, has proved to be an effective mechanism for the management of water under conditions of scarcity, which by definition is when a market can be created. In any case, analysis of the application of this mechanism shows that the flows compromised are not very large. In addition, there is the ethical question of granting added value to a private individual who owns the concession when selling or leasing a right that the state granted at no cost.

In Colombia, where water supply is abundant, the usefulness of mechanisms such as those described above is unclear. Instead, programs to create awareness of the importance of water and for the application of mechanisms for surveillance and control of concessions and discharges might be considered. Also available are instruments such as use and compensation fees that encourage the rational use of water and promote cost-benefit equity in the use and maintenance of a resource of public interest that the state concessions at no cost. An interesting option for Colombia could be that the landowners where water resources originate or where important ecosystems for environmental conservation are found, could obtain concessions to maintain hydrological supply by leasing these rights to owners downriver so they can carry out their profitable tasks.

Parts of the instruments for efficient water management are effluent and natural resource fees, created to rationalize the behavior of consumers searching for water of good quality. In our country, the potential of these instruments has not been satisfied and unfortunately they have not affected water quality and quantity. Again, the criterion of fairness, which implies the fulfillment of the "paying pollutant" principle, comes to mind, in such a way that the consumer pays the costs of water treatment to make it apt for reuse.

Granting concessions for the various uses of water implies recognizing the size and variation of flow and its quality. In order to determine the amount of flow available for a variety of uses, current social priorities must be considered. The first of these is use by humans, followed by agricultural and industrial uses and finally the generation of hydroelectricity. Unfortunately, ecological flow is rarely recognized as important and is often ignored, however being the flow that a current must carry to guarantee its proper functioning within an ecosystem, it is fundamental.

The reuse of water is an interesting alternative, given the growing demand of water for consumptive and nonconsumptive uses, as long as the water returning to the environment fulfills the standards required for its future uses. This possibility stimulates wastewater treatment whenever the consumer benefits for using and treating water before returning it to the environment.

Although water for drinking is the most obvious and relevant of its uses, it only represents about 5% of its total consumption. The market for drinking water has reached unsuspected dimensions that seem unreal and artificially created by an obsession with quality and health. Bottled water in the United States for example, creates an annual market of 7 billion dollars and its value has increased 80 times between the years 1970 and 2000. Its price is several times greater than the price for milk or gasoline, and even more than the price of soda, which is made from water. This is not the only market for water, but it is the most developed.

Agriculture consumes around 60% of the water we use and its demand continues to rise, motivated by an ever growing population with an increasing income, and a supply that continues to fall because of decreased availability and quality. Traditional irrigation systems are greatly inefficient and poorly used, causing very serious effects on soil. This opens the field to the development and spread of sustainable and technified systems which offer an enormous potential in the saving of water and money. The use of drop irrigation and automatic systems, amongst others, provide an important opportunity to save water.

The future also offers other very interesting possibilities if we not only consider water as a fundamental element for life, but also as a strategic resource. In this way, Colombia could make the most of its natural hydrologic wealth and turn it into a factor for sustainable development.

Possible nonconventional uses of water in our country include hydro energy, resulting from the country's water abundance and pronounced relief which might allow electricity to be exported to Central and South America, and water itself to be marketed for human, agricultural and industrial use.Naturally these possibilities should primarily regard national interests, as water is a public good that should benefit Colombians first and foremost, and must be developed by means of highly efficient and low impact technology. Projects should be based on design and operation criteria that avoid the devastating effects of enormous dams on ecosystems and communities. True and active participation of the communities affected by projects is fundamental to this new approach, as is the harmonization of the projects themselves with regional and local planning strategies, for aspects such as organization, management and development by territorial entities and environmental authorities.

In addition, projects should have a multiple purpose, including conservation, recreation, ecotourism and fish farming, to allow the local people to achieve economic benefits and improve their quality of life. They should not however compete with the watershed's water requirements to satisfy the various uses and the adequate function of ecosystems.

The possibility of exporting the water surplus form various parts of the country for uses such as agriculture or industry in countries with water shortages, is worth exploring deeply. To grant economic value for the maintenance of environmental conditions to "produce" water permanently and sustainably could be an attractive alternative to stimulate conservation. Thus conservation would imply the productive use of land, the generation of income for communities and owners of the areas, and avoidance of deforestation and predatory uses such as ranching and cultivation of unsustainable and illegal crops.

20. Conclusions

The situation of hydrological resources in Colombia in general has not reached the critical levels found in other countries. However, there are symptoms that cause alarm with respect to supply in certain municipalities and urban areas where it is necessary to define policies for planning, management and use of hydrologic resources to avoid crisis in the future. In the coming years, not only will the demand for water for human and economic purposes continue to increase, but the usable supply of water could fall if the current tendencies of deforestation and the almost absolute absence of sewage treatment continue.

Colombia in summary, disposes of very significant amounts of water to satisfy its needs. The enormous problem that seems to be approaching has to do with the quality of water, not with its scarcity. In other words water related problems depend more on management and control than on its natural availability. In this sense for decision making is essential to better planning tools such as those currently proposed national policy for water management and national survey instruments such as water, allowing progress in the analysis of information to identify the state of the art of water resources in our country.

The national survey of water (IDEAM, 2010) mentioned the need to strengthen monitoring and information systems to obtain more timely and representative of reality. It is also necessary to advance in studies of groundwater, as they are an essential resource for water supply for future generations, taking into account the decrease in availability of surface water to meet water demands of our population.

Climate change is a fact to take into account when analyzing the information, and Colombia is no exception, since the effect of natural climate variability today, raises huge risks to social and economic sectors, because the intensity of the events that have been presented in recent years. For this reason, future analysis should take into account the projections of water before scenarios of climate variability and changes in land use and land cover.

The IDEAM should develop strategies for adaptation to current climate variability of the country within the management plans and land and water resources, strategies that would be in favor of increasing resilience to climate change. It is expected that developments in policy terms, as proposed by the National Policy for Integrated Water Resource Management, to enable better planning and control of water resources, but the dismantling institutions and sectors, calls into question their effectiveness and becomes a potential threat to the care and protection thereof.

21. References

1. Allen, R. N., 1972. The Anchicayá hydroelectric project in Colombia: design and sedimentation problems. En: M. T. Farvar y J. P. Milton (Eds). The careless technology. Ecology and International Development. Natural History Press: 318-342.
2. Contraloría General de la República. Estado de los recursos naturales y el ambiente 2007-2008. Editorial Imprenta Nacional, mayo de 2007.
3. Guhl Nanneti, Ernesto. La Gobernanza del Agua, ¿Pública o privada? Diario El Tiempo, 19 de marzo de 2009.
4. Guhl Nanneti, Ernesto. "El agua en el futuro sostenible de Colombia: para que queremos el agua?". Economía Colombiana Ed. 312, Revista de la Contraloría General de la Republica, mayo de 2006.
5. Hernani, A. y J. J. Ramírez, 2002. Aspectos morfométricos y teóricos de un embalse tropical de alta montaña: represa La Fe, El Retiro, Colombia. Revista de la Academia Colombiana de Ciencias, 26(101): 511-518.
6. IDEAM-Instituto de Hidrología,

Meteorología y Estudios Ambientales. El medio ambiente en Colombia. 2da. Edición, Bogotá, agosto de 2001.

7. IDEAM, 2005- Instituto de Hidrología, Meteorología y Estudios Ambientales, Estudio Nacional del Agua..
8. IDEAM. Informe Anual sobre el Estado del Medio Ambiente y los Recursos Naturales Renovables en Colombia, Estudio Nacional del Agua – Relaciones de Demanda de Agua y Oferta Hídrica, 2008.
9. IDEAM- Instituto de Hidrología, Meteorología y Estudios Ambientales. Estudio Nacional del Agua. 2010.
10. IDEAM. El Estudio Nacional del Agua un Compendio sobre el Recurso hídrico en Colombia, Efraín Antonio Domínguez Calle, Grupo de Investigación en Hidrología, noviembre de 2005.
11. IDEAM. Presentación Mitos y realidades sobre el consumo de agua en Colombia, Hebert Gonzalo Rivera, Ingeniero Hidrólogo, Ph. D., Subdirección de Hidrológica, Barranquilla, 2007.
12. IDEAM. Los Glaciares Colombianos expresión del Cambio Climático Global, 1998.
13. IDEAM – UNAL. Estudio de Alta Montaña Colombiana, 1997
14. Mancera, N. y P. Cala 1997. Aspectos bioecológicos de la comunidad íctica asociada a un cultivo de tilapia roja enjaulas flotantes en el embalse de Betania, Colombia. Dalia Revista de la Asociación Colombiana de Ictiología 2: 31-53.
15. Márquez, G. y G. Guillot. 2001. Ecología y efecto ambiental de embalses. Aproximación con casos colombianos. Universidad Nacional de Colombia, Medellín. 218p.
16. Medina, H. 1983. Problemas de operación de origen ambiental en la Central Hidroeléctrica de Guatapé. Revista EE.PP.MM, 5(1) 53-77.
17. Orozco, A. 1981. Fósforo y eutroficación en la protección de los recursos hidroenergéticos del departamento de Antioquia. En: Revista AINSA No. 1, Año 1, Agosto 1981.
18. Ramirez, J. J. 1999. Limnología de represas de altitud en Colombia con énfasis en los embalses la Fe y El Peñol. Ecología de Reservatórios. 4: 79-107.
19. Ramirez, J. J., C. Bicudo, G. Roldán y L.C. García. 2000. Temporal and vertical variations in phytoplankton community structure and its relation to some morphometric parameters of four Colombian reservoirs. Caldasia 22(1): 108-126.
20. Ramirez, J. J., C. Bicudo, G. Roldán y L. C. García. 2001. Variación vertical de parámetros físicos y químicos en cuatro embalses tropicales y su relación con el área, la altitud y el tiempo de retención hidráulica. Acta Limnol Bras., 13:19-34.
21. Roldán. G., 1978. Problemas de eutroficación en lagos y embalses colombia-nos. Revista Cont. Amb. 2(3): 51-56.
22. Roldán, G. 1982. Algunas consideraciones ecológicas acerca de los embalses. Rev. Cont. Amb. 6(10): 13-20.
23. Roldán, G., M. Correa, T. Machado, J. J. Ramírez, L. F. Velásquez y F. Zuluaga,

1984. Estudio Limnológico de la represa El Peñol. Actual. Biol. 13(50): 95-105.
24. Roldán, G. 1988. Guía para el Estudio de los Macroinvertebrados Acuáticos del Departamento de Antioquia. Fondo FEN-Colombia, Ed. Presencia Ltda., Bogotá. 217p.
25. Roldán, G. 1992. Fundamentos de Limnología Tropical. Ed. Universidad de Antioquia, Medellín. 529p.
26. Roldán, G., A. Bohórquez, R. Castaño y J. I. Ardila, 2000. Estudio limnológico del embalse de El Guavio (Colombia). Revista de la Academia Colombiana de Ciencias Físicas, Exactas y Naturales. XXIV (90): 73-84.
27. Roldán, G y E.Ruíz, 2001. Development of Limnology in Colombia. In: Wetzel, R y B. Gopal: Limnology in Developing Countries. 3: 69-119. International Association of Theoretical and Applied Limnology-SIL.
28. Roldán, G. 2002. Treating industrial wastes in Colombia using water hyacinth. Waterlines.21(1).6-8.
29. Roldán, G. 2003.La bioindicación de la calidad del agua en Colombia. El método BMWP/Col. Ed. Universidad de Antioquia, Medellín. 170p.
30. Roldán, G y J.J. Ramírez, 2008. Fundamentos de limnología neotropical. 2da.Edición. Ed. Universidad de Antioquia, Medellín 440 p.
31. Salazar, A. y R. Díez de Arango. 1987. Control de plantas acuáticas en el embalse La Fe. Revista AINSA (Medellín) 2: 7-31
32. Sierra, O. y J. J. Ramírez. 2000. Variación espacio-temporal de biopelículas asociadas a sustratos artificiales en la represa La Fe, El Retiro, Antioquia (Colombia). Actual. Biol.. 22: 153-168.
33. Universidad de los Andes, MAVDT, — Bases para la formulación de un Plan Nacional de Aguas Residuales, 2002.
34. Uribe, A. y G. Roldán, 1975. Estudio comparativo de algunas características fisicoquímicas y biológicas del embalse El Peñol (Nare). Actual. Biol. 4(11): 2-12.
35. Valderrama, M., 1984. Análisis de la situación actual y perspectivas de desarrollo pesquero en embalses de Colombia. Divulgación Pesquera, Inderena, Bogotá. XXII (2, 3, 4): 72-91.
36. Valderrama, M. 1985. Embalses y problemática pesquera, Colombia. Ciencia y Tecnología. Vol. 3(3): 11-14, Colciencias, Bogotá.
37. Vargas, R. A. y J. J. Ramírez. 2002. Variación espacio-temporal de las tasas de sedimentación del material sestónico en un embalse tropical de alta montaña: represa La Fe, El Retiro, Antioquia, Colombia. Actual. Biol. 24(77): 13-170.
38. Vega, E. R. Díez y O. Ruiz. 1992. Limnología de dos embalses del oriente antioqueño. Contaminación Ambiental (Antioquia) 13: 10.
39. http://aupec.univalle.edu.co/informes/abril97/paraiso.html


Waterfall La Fortuna

Water Resources in Costa Rica
A Strategic View

Hugo G. Hidalgo[1,2]

[1]Escuela de Física, Universidad de Costa Rica

[2]Centro de Investigaciones Geofísicas, Universidad de Costa Rica

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1. Introduction

A diagnostic of the state of the terrestrial water resources of the Republic of Costa Rica is presented. Compared to the large number of countries in the world, Costa Rica has an ample availability of water (around 25,900 m^3/ yr / inhab), and very low percentage use (around 2.4%).

This makes Costa Rica a country with a very low water stress. However, these national averages are poor indicators of the potential for further exploitation and of the situation of stress in some regions in terms of supply and quality of water resources.

In fact, when constraints such as conservation of water to ensure sustainability of natural resources and socioeconomic development are included, the adequate percentage water use for some regions could indeed be a very low number.

The fact suggests that more and better integrated catchment management and planning studies are needed in order to optimize the use of the water resources.

Over the last 20 years, the country has been recognized as a very eco-friendly country, thanks to its forest conservation efforts and the protection of ecosystems; but this contrasts with grave new and old environmental problems, such as the severe contamination of urban streams and aquifers. Although some of these decades-long problems are finally beginning to be addressed, there is much to be done in near future. Better integrated catchment management and planning studies and systems are needed. Protecting the natural resources of the country for future generations is a significant challenge that will require the support, consensus and coordination of many sectors of society.

2. Background

The Republic of Costa Rica obtained its independence from the Spanish Crown in 1821, and is considered the oldest and more solid democracy in Latin America. Although since its emancipation there have been some disruptions of the institutional order (like the rest of the countries in the region), since 1948 the country consolidated a democratic system that is considered exemplary in the world.

Historically, water has participated in the social, economic and cultural development of Costa Rica, but its relative abundance created the impression that it was an infinitely renewable resource. However, history shows that the quality of the water resources has been changing over time with grave consequences for the humans and for the environment.

Water was a natural resource of great importance for the development of aboriginal's societies before the arrival of the Spaniards, used for transportation, food production, and for religious rituals. With the arrival of the Spaniards the availability and quality of the resource changed dramatically, partially associated with deforestation (Vargas Sanabria, 2003).

Agricultural production (especially coffee and bananas) formed the basis of the early development of the country and continue to be important today. In the 19th century, the development of agro-industry associated with the processing of coffee, bananas, sugar and sugar-cane liquor increased the demand of water and started the pollution of rivers. However, over the years, part of the wealth from this production was well spent, as it helped finance the early education and health systems. The smart decision of abolishing the army in 1948 was the key for keeping the country politically stable and allowed more economical resources to be spent on social programs. Water supply and sanitation programs benefited from these funds that otherwise would have been spent on arms. Sadly, the lack on environmental conscience also allowed that the development of Costa Rica in large part of the 20th century was done without any regard for water quality in streams, and for conservation of forests or soils. Fortunately, this started to change at the end of the 20th century, and now Costa Rica has earned a good reputation as an environmentally-friendly country. This contrasts with the severe contamination problems that still persist in the urban streams for example. While it will probably take a continuous effort over many years to address all the local problems related to deforestation, over-exploitation and quality of water resources, there are indications that emerging efforts to clean the environment and insure sustainability are starting to take place. This is a significant challenge that will require the participation of many sectors of the society, but that will also result in a better quality of life for future generations.

3. National Fresh Water Resources and Use

Costa Rica is located in the southern part of Central America. The continental part of the country can be framed between 8°02' 26" to 11°13' 12" latitude North and 82°33' 48" to 85°57' 57" longitude West (FIG. 1, INEC, 2004). Costa Rica presents a range of elevations from 0 meters above sea level (MSL) in the Pacific and Caribbean coasts to 3,810 MSL in the Cerro Chirripó, the tallest peak in the Talamanca Mountain Range that delineates the continental divide in the southern part of the country. Costa Rica extends over approximately 51,102 km^2 and is divided in seven provinces: San José (SJ; 4,966 km^2), Alajuela (AL; 9,758 km^2), Heredia (HE; 2,657 km^2), Cartago (CA; 3,125 km^2), Puntarenas (PU; 11,266 km^2), Limón (LI; 9,189 km^2), and Guanacaste (GU; 10,141 km^2). A small island (of around 24 km2) in the Pacific Ocean (05°31' 08" North and 87°04' 18" West) known as "Isla del Coco" or "Coco's Island" is also under national sovereign since 1869. The 2008 estimated total population in the country was 4,451,262 habitants (INEC, 2008) and the Gross Domestic Product was estimated in around US$ 29,800 million (COMEX, 2008).

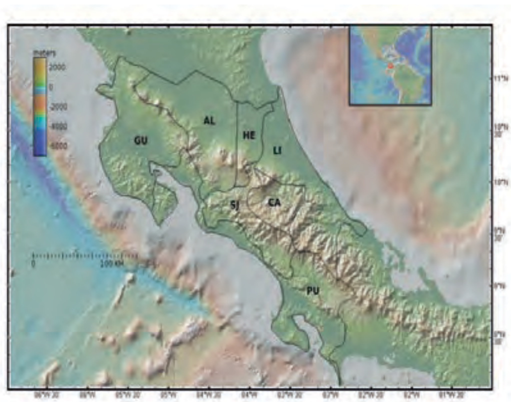


FIG. 1. Boundaries and Internal Administrative Division of the (Continental) Republic of Costa Rica. The Country is Divided in Seven Provinces: San José (SJ), Alajuela (AL), Heredia (HE), Cartago (CA), Puntarenas (PU), Limón (LI), and Guanacaste (GU).

Costa Rica is located in the Neotropic or Neotropical ecozone, having an intertropical (tropical and subtropical) climate that results in a relatively large availability of rainfall during large part of the year in a large part of the country. Dry season in large part of the country extends from December to April and consequently the rainy season extends from May to November.

The country's rich topography, exposure, distance to the coast, and seasonal prevailing atmospheric circulation patterns results in high spatial and temporal precipitation variations and relatively abundance of contrasting micro-climates (see also Amador et al., 2000). For example, average annual total precipitation ranges in the order of less than 1.5 m in the Guanacaste coastal plains and Cartago's valleys, to more than 8 m in the Talamanca Mountain Range, with a national average of around 2.9 m (UN, 2006). Average annual temperature ranges from slightly less than 5° C in the top of the highest mountains to more than 28°C in Guanacaste's lowlands (IMN, 1985; UNESCO, 2007) but with relatively small seasonal change. Average annual total annual renewal water resources (TARWR) have been estimated in around 112 km3 (UN, 2006; Peter H. Gleick and associates, 2008; CIA, 2009) or more than 25,900 m3 per year per habitant in the majority of consulted studies; although some figures could be as high as 170 km3 (Ministerio de Salud and Organización Panamericana de la Salud, 2003; Vargas Sanabria, 2003).

This suggests that on average, Costa Rica has an absolute ample availability of freshwater. Except perhaps for countries in South America and Oceania, many countries of the world and in the region have considerably less TARWR (FIG. 2).

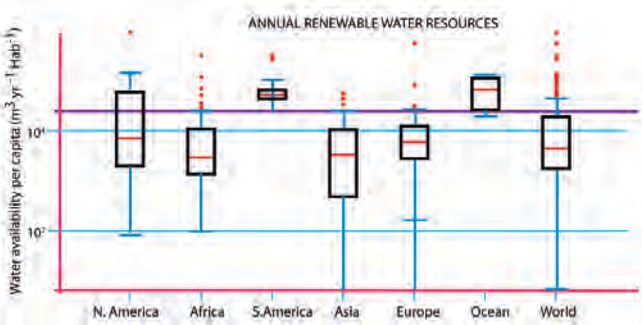
However, as it will be discussed below in this and following sections this large average water supply availability hides serious local over-exploitation problems and severe cases of contamination of urban rivers and aquifers, mainly associated with uncontrolled growth (see for example OD, 2001).

In the last couple of decades, the accumulation of new and old water supply and water quality problems, (some of them which resulted in an increased incidence of local water conflicts OD, 2001), and the development of a better environmental conscience in the habitants (associated with a global and local increase in the awareness of the necessity and value of environmental protection) have helped to start reducing the apathy in the society (see also Monge Flores, 2009). Unfortunately, there are serious obstacles that have to be faced in order to solve these problems, not only of economical nature, but also due to the lack of 1) appropriate legislation, 2) inadequate institutional framework, and 3) ways or genuine desire to reach consensus to protect the natural resources (see also Programa Estado de la Nación, 2009). About two-thirds of the TARWR is available as surface water and one third as groundwater (UN, 2006). There are a total of around 13 main water basins in the country. Four of them drain to the Pacific Ocean, three drain to the San Juan River which delineates part of the northern border of Costa Rica with Nicaragua, and the remaining six drain to the Caribbean (Table 1).

From these 13 basins, there are 44 small sub-basins including 4 from the Isla del Coco. In terms of groundwater, the main aquifer in the Caribbean is called "La Bomba" located in the left margin of the Banano River. The northern drainage basin has not been studied and there is not much hydro-geological information.

Table 1. Main Rivers of Costa Rica. Data not Available are Indicated with the "N.A." Abbreviation. Source: Ministerio de Salud et al., 2003.

Drainage basin	Name	Length (km)	Watershed area (km^2)
Pacific	Tempisque	136	3,400
	Grande de Tárcoles	94	2,150
	Parrita	108	1,273
	Grande de Térraba	160	5,000
Atlantic	Reventazón-Parismina	145	3,000
	Pacuare	108	882
	Matina-Chirripó	92	416
	Banano	N.A.	204
	Estrella	52	1,002
	Sixaola	146	2,700
Northern (San Juan river)	Frío	52	1,551
	San Carlos	135	2,650
	Sarapiquí	84	2,150



The thick horizontal line corresponding to around 25,900 m^3 yr-1 hab-1 is the estimated value for Costa Rica, N. America: Includes countries from North America, Central America and the Caribbean and Ocean includes the countries from Oceania and Australia. The population data is for 2005, but the water availability data vary from 1997 to 2005. It is assumed here that the water availability does not chnge significantly from year to year. The box are composed of the 25th, 50th (median) and 75th percentiles. The wiskers extend up to 1.5 times the interquartile range or to the extent of the data. Values outside the whiskers are considered outlers and shown wirh a dot symbol. This figure was constructed using data from Peter H. Gleick and associates (2008) under permission.

FIG. 2. Average TARWR Per Capita for Different Regions of the World.

The main aquifers of the Pacific drainage basin are located in the Tempisque, Grande de Térraba and Barranca rivers (Table 2; Ministerio de Salud et al., 2003). There are four zones that concentrate the larger part of groundwater demand: 1) the Large Metropolitan Area (LMA) of the capital of San José and other neighboring cities (representing 2.4 million habitants and 4% of the area of Costa Rica in 2005), 2) Guanacaste, 3) Puntarenas and 4) Limón.

Around 50% of the total water supply for human consumption on these areas comes from groundwater sources. In particular, the most exploited aquifers in the country (Colima Inferior, Colima Superior and Barva) supply water to more than 65% of the LMA (Ministerio de Salud et al., 2003).

Table 2. Main Aquifers Currently Exploited in Costa Rica. Data not Available are Indicated with the "N.A." Abbreviation (Adapted from OD, 2001).

Name	Extraction volume ($x10^{-3}$ m^3 s^{-1})
La Bomba (Limón)	30
Río Moín (Limón)	N.A.
Santa Clara (Alajuela)	10
Bagaces (Guanacaste)	380
Tempisque (Guanacaste)	50-100
Barranca (Puntarenas)	N.A.
Colima Inferior (San José)	80
Colima Superior (San José)	750
Barva (Heredia)	20-100

Costa Rica can be considered a country with relatively low water stress (5.1%). However, this national average hides dramatic contrasting situations. For example, the extraction index from groundwater around the capital metropolitan area rose from 16% to 62.5% between 1996 and 2000. This is equivalent of a water stress similar or greater than the values observed in Egypt, Libya, the Arab Peninsula and the Near East (Fernández-González and Gutiérrez-Espeleta, 2002; UNEP, 2003). Unfortunately, due to the lack of assessment studies and data, the degree of the prevalence of similar cases of local water resources over-exploitation problems is ultimately unknown. However, the problem seems common in Costa Rica, implicating inadequate or in many cases inexistent integrated catchment management and planning programs of water resources in the country, which has implications for the environment, future availability, sustainability of natural resources and the quality of life.

Some of the reasons behind this suggestion are: 1) as previously mentioned, the large availability of precipitation and low water stress in the majority of the country resulted that over the centuries the Costa Rican society have not worried much about water scarcity, and have not put enough value on adequate water resources planning and management for a long time (Ministerio de Salud et al., 2003); although this changed dramatically, due to this old mentality, serious problems accumulated over the years; 2) with exceptions (i.e. MIVAH et al., 2006; MINAE and IMN, 2007 and other publications from the same project) there is a lack of integrated studies on water resources to guide planning and to provide knowledge about the maximum amount of water that could be devoted to a certain use or that could be extracted from a particular river system or aquifer to guarantee sustainability (UNEP, 2003; Tribunal Latinoamericano del Agua, 2008); 3) the quality and quantity of hydro-geological data from aquifers has to be improved and more hydrological data (i.e. stream flow measurements, soil moisture and land surface information such as vegetation cover and soil properties) are needed in order to produce appropriate water resources assessments; 4) the assignment of water rights are not consistent with an integrated catchment assessment that considers different human uses (i.e. water supply, agricultural, industrial) and other flow requirements (i.e. environmental, flood control, optimal reservoir operation, hydropower generation, ecological, water quality); and that incorporate aspects such as sustainability, climate change, monitoring, reforestation, land use and other related issues; 5) in practice, the construction and monitoring of private wells (especially in rural areas) have little or no control (Tribunal Latinoamericano del Agua, 2008); 6) water laws are old and outdated; and 7) fast and disorganized urbanization and forest clearing due to the lack of territorial ordination laws and guidelines creates great pressure over the environment and water resources on certain regions (Programa Estado de la Nación, 2009), and also puts pressure on the land of headwaters that feed rivers and aquifers (MINAE et al., 2007; Moreno Díaz, 2009; see also OD, 2001).

4. Water Balance

A few years back the United Nations Educational, Scientific and Cultural Organization (UNESCO) supported an effort to estimate the national water balance of countries around the world using a common methodology. In Costa Rica, the Costa Rican Electricity Institute (ICE in Spanish) was responsible of generating the national study. ICE studied 34 basins that covered a large part of Costa Rica's territory and in 2007 produced a 1970-2002 water balance estimate of each basin's average total annual precipitation, runoff, actual evapotranspiration (AET) and balancing error using the following equation (UNESCO, 2007).

$$P - Runoff - AET + error = 0 \qquad \text{(Equation 1)}$$

Where P, Runoff and AET are the temporal and spatial average of each basin's annual accumulated precipitation, runoff and actual evapotranspiration respectively, and error is the required term to make the left side of the equation equal to zero (UNESCO, 2007).

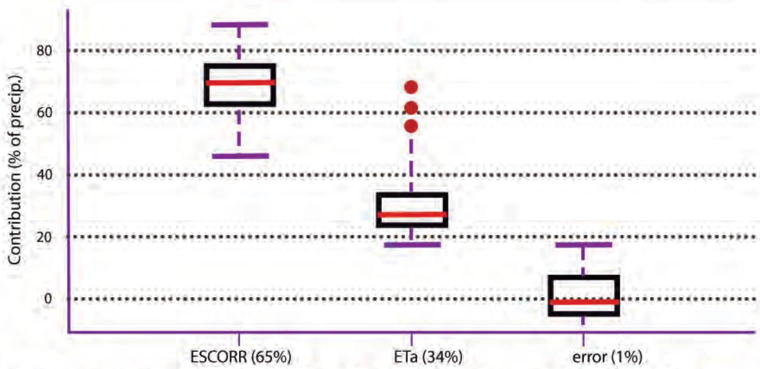
In FIG. 3, the data from UNESCO, 2007 were used to calculate the average percentage contribution of runoff and AET compared to the total precipitation in a year, along with the estimate of the error term. As can be seen, the two water balance components and the error have comparable spatial variability.

The basin's area weighted estimates show that a relatively large part of precipitated water usually becomes runoff (65%), while AET is about one third of precipitation (this figure is consistent with Ministerio de Salud et al., 2003). The error term is generally low (1%), suggesting that the assumptions about storage at these time scales are generally valid in these basins. It should be noted that the Runoff component indirectly includes recharge water to the aquifers, as recharge was not considered explicitly in the analysis. It has been estimated that around 21% of the annual water is used for groundwater recharge that could in turn become stream flow downstream from the recharge areas (Ministerio de Salud et al., 2003).

5. National Water Uses

Total annual water use is estimated to be as low as 0.54 km^3 or 0.5% of the TARWR (Ministerio de Salud et al., 2003 to as high as 2.68 km^3 or around 2.4% of the TARWR (UN, 2006; Peter H. Gleick & associates, 2008; CIA, 2009). This latter figure corresponds to about 619 m^3 yr-1 per capita (in 2000), distributed in 29% domestic use, 17% industrial use and 53% agricultural use (Peter H. Gleick and associates, 2008; CIA, 2009). FIG. 4 shows a comparison of the percentage use of water resources for Costa Rica against the distribution for several regions of the world. As can be seen, per capita water use in Costa Rica is significantly below the median of many regions of the world except for South America and Oceania.

About twice the volume of water used for agriculture is used for hydropower generation, but since this water is returned to the river it is not considered here as part of the estimated 2.68 km^3 water consumption. There are hydropower plants of diverse capacity in about 38% of the basins (UNA, 2004). As it is the case in many other regions of the world, agricultural production is the greatest consumer of water. Unfortunately, Costa Rica has the greatest consumption of agrochemicals in the Central American region, with consequent negative impacts in the environment (flora and fauna), soils, streams and aquifers (UNA, 2004). It is estimated that Costa Rica has around 5,250 km^2 of land that could be potentially irrigated, but only around 17% has some kind of irrigation infrastructure or are currently irrigated. The majority of the systems are based on gravity with a very low efficiency. Surprisingly, the water is priced according to the irrigated area and not according to the total volume, which favors a high-demand system, low efficiency and little incentive for upgrading the systems (UNA, 2004).



The average contribution to the water balance of each of the components is expressed as percentages of annual accumulated precipitation. The values in parenthesis are the averages weighted by the each basin's area. Runoff corresponds to surface runoff, AET is actual evapotranspiration and error is the value necessary to close the water balance (as shown in Equation 1). The explanations of the boxes are the same as in FIG. 2. This figure was constructed using data from UNESCO, 2007 under permission.

FIG. 3. Water Balance of 34 Costa Rican Basins from 1970-2002.

Forms of industrial use of water includes: 1) ingredient in the production processes in diverse industries such as bottling of water, production of drinks (soft drinks, juices, liquors), 2) purification of high technology components, and many others, 3) transport of products, 4) maintenance and cleaning of equipment and infrastructure, 5) in the case of the tourism industry a fraction of the water is also used for providing recreation, and 6) other related uses. Due to the lack of treatment plants, there is a considerable impact of industrial (and domestic) residual water in the environment (UNA, 2004). It should be recognized, however, the efforts of certain sectors of the industry to reduce water use and to adopt adequate practices, which includes certifications in accordance with environmental norms (UNA, 2004).

6. Water and the Environment

The relatively low water use compared to the TARWR and the high average TARWR shown in FIG. 2 and FIG. 4 could be misleading indicators of the potential amount of additional exploitation that can be sustainable or desirable for a certain region. For example, the report Programa Estado de la Nación, 2009, an annual national diagnostic study that evaluates many variables affecting socioeconomic development of the country, included for the first time an estimation of the "ecological footprint" of the country. The results are distressful, as they show that the rate of use of natural resources is greater than the capacity of the national territory for replenishing them by around 12% (therefore in order to satisfy the needs of each person we would need 12% more land of what is currently productive), and this has implications for environmental sustainability. This also means that the country depends on external natural resources and that it is in fact in "ecological debt". The increasing pressure on natural resources could result in serious loses in the availability and quality of natural resources (key components of the national development); which in turn could compromise even more the environmental sustainability and the quality of life of future generations (Programa Estado de la Nación, 2009).

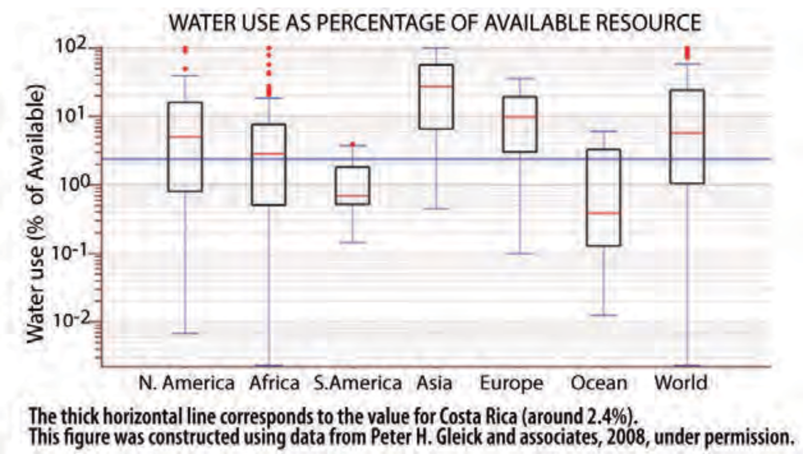


FIG. 4. Average Percentage Use of Available Water Resources.

Although this debt is well below the world mean of 30% (above the capacity of the planet), or to the estimates for countries with less resources (El Salvador = 125%) or higher consumptive patterns (United States = 88%), it still constitutes a significant percentage (Programa Estado de la Nación, 2009). In the Programa Estado de la Nación, 2009 two types of actions are suggested to be implemented in the near future in order to reduce Costa Rica's ecological debt: 1) it is urgent to set up a territorial ordination system that will allow a better distribution and management of the natural resource, and 2) due to the relatively high weight of the carbon gas emissions in the calculation of the ecological footprint, Costa Rica must improve the public and private transportation systems (Programa Estado de la Nación, 2009).

External water use constraints such as the ones imposed by the necessity of protecting terrestrial and aquatic ecosystems, or achieving sustainable development may interact with other type of constraints which could result in a strong limitation in the percentage water (from the total availability) that can be extracted from a particular region. A corollary of this is that the maximum percentage water use in order to guarantee sustainability of the overall natural resources, to fulfill the water necessities for other unrelated diverse water uses of a region and its dependent external ecosystems (under certain management conditions) could perfectly be a very small number, and that the perception generated by the relative abundance of water at the national level, may be misleading in terms of the extra amount of exploitation that can be justified in a certain region. The expression: "water in Costa Rica is abundant but vulnerable" (OD, 2001) somewhat summarizes this idea.

As recognition of the historical ecological conservation efforts, in the last couple of decades, Costa Rica has been considered a country generally concerned with the environment. Contrasting with this image, however, all the urban streams and also many aquifers and soils are severely contaminated with solid waste and wastewater from different sources, including a large amount of sewage that is discharged to the rivers without any kind of treatment at all (Table 3). There are also severe cases of groundwater contamination identified in diverse studies that report nitrate concentrations in urban settings that are almost twice the recommended values by the World Health Organization (OD, 2001). Septic tanks are usually constructed without knowledge of the water table levels, and therefore contamination of groundwater sources with fecal material may be a generalized problem in urban regions (Moreno Díaz, 2009).

The LAM presents the most serious problems of water resources degradation and these effects extend beyond the limits of the cities, as large rivers (i.e Grande de Tárcoles River) transport heavily polluted waters from the cities all the way to the ocean, severely affecting coastal and marine ecosystems. Also, problems are starting to arise in rural communities due to the rapid development of towns and cities outside the LAM; in particular in Guanacaste, which has developed a large touristic industry over the last 15 years at an impressive increasing rate.

Historically, agricultural activities have also contributed greatly to the contamination of streams. For example, in the beginning years of the 1990's it was estimated that around 68% of the total water contamination of the Central Valley was associated with coffee growing activities. In the worst times of those years the daily biochemical oxygen demand for the Grande de Tárcoles river reached 260 tons, or the equivalent pressure that could be exerted by the organic waste of a population of 47 million people, which constituted around 15 times the total population of Costa Rica. During that time, concerns about this severe contamination resulted in new regulations and programs that reduced the contaminant loads by around 45% in 1998.

However, as can be seen in the worrisome results in Table 3, these early efforts have only contributed marginally to solve the large and complex problem of water quality in the Grande de Tárcoles and Virilla urban rivers, and there is much to be done in future years.

Fortunately, there are indications that efforts are underway to finally move forward into solving part of these problems that have been affecting the population for decades. For example, a project called "Improvement of the Environment of the Large Metropolitan Area of San José", approved by the Law 8559 in 2006 is aimed at restoring water quality of the most polluted rivers of the LAM.

The project is under administrative responsibility of a "Project's Executive Unit" integrated by members of the Japanese Bank for International Cooperation and the Costa Rican Institute of Aqueducts and Sewers (AyA in Spanish); the local institution in charge of drinking water supply, sanitation and disposal (AyA , 2007; OD, 2001). In the first phase of the project a large water

Table 3. Average Concentrations for Several Water Quality Indicators in Two of the Most Polluted River Systems of the LAM from 1997 to 1999. Maximum Allowed Concentrations are Shown in the Headings. TOC: Total Organic Carbon, BOD: Biochemical Oxygen Demand, COD: Chemical Oxygen demand, DO: Dissolved Oxygen, FC: Fecal Coliforms, A: Ammonium, and P: Phosphorous.

Monitoring point	TOC (1.5-2.5 mg/L)	BOD (3-5 mg/L)	COD (10 mg/L)	DO (4mg/L)	FC (200/100mL)[a]	A (0.5mg/L)[b]	P (1.5-2.5mg/L)
Rio Virilla (western San José city)	13.60	19.00	62.5	6.20	4,246 k	3.65	667.66
Río Grande de Tárcoles confluence with Río Virilla	9.01	13.89	33.00	6.20	168 k	1.21	0.47
Río Grande de Tárcoles Outflow to the ocean	7.08	14.29	42.20	6.32	107 k	0.92	4.95

a: For irrigation use

b: Recommended value = 0.05 mg/L

treatment plant will be built from 2010 to 2012, which would eventually process the polluted waters from 65% of the LAM population, or around 1,070,000 people. This would result in an improvement in water treatment coverage from 3.5% to around 27%. In the second phase, the coverage will be augmented to around 1,600,000 people. The resulting treated water will have 90% less contamination compared to current loads and will meet current national regulation (Chaves, 2009).

Among other efforts, studies have been developed since 1989 to determine the quality of water in the aquifers of the Central Valley, based on continuous monitoring. The project has been developed with the participation and coordination of various institutions including AyA, Servicio Nacional de Riego y Avenamiento (SENARA), the International Atomic Energy Agency (IAEA) and the Universidad Nacional (UNA). Part of the activities includes monitoring several rivers and wells in the metropolitan area to assess correlations with groundwater. Groundwater pollution sources have been identified through analysis of O18 and N15 (Salazar, 1998).

7. Drinking Water, Sanitation and Health

In 2008 around 83% of the population had access to potable (drinking) water and more than 99% of the population had access to water suitable for human use such as bathing, cooking, sanitation, and gardening (Programa Estado de la Nación, 2009). In 2004, about 92% of the population had access to some form of sanitation service, compared to the 1970 value of 52% (Peter H. Gleick and associates, 2008). However the 2000 estimations also showed that 64% of the population had septic tanks (instead of access to a sanitary sewer system) as the only mode of sewer disposal, and this percentage tended to increase over the years (OD, 2001). The septic tanks are a source of groundwater contamination due to the infiltration of pathogens and nitrates into the soils. Conversely, the sanitary sewer systems that include treatment plants prevent ground and surface water contamination. The large percentage of septic tanks is therefore an indication that addressing the problem of groundwater contamination will probably be a complex and costly endeavor.

The relatively high availability of clean water along with the opportune investment in public health in the past could be considered two of the reasons behind the relatively good health indicators of Costa Rica compared to other countries in Latin America and the Central American regions. However, the degradation of the environment and water bodies in the country, but particularly in the LAM over the last three decades is beginning to be increasingly costly in human and economic terms. In fact, it has been estimated that the annual costs of pollution in terms of loss of productivity and treatment of associated diseases total about US$325 million divided in US$122 million from the areas of the cities connected to the sanitary sewage system, plus US$203 million from the areas with septic tanks (Moreno Díaz, 2009).

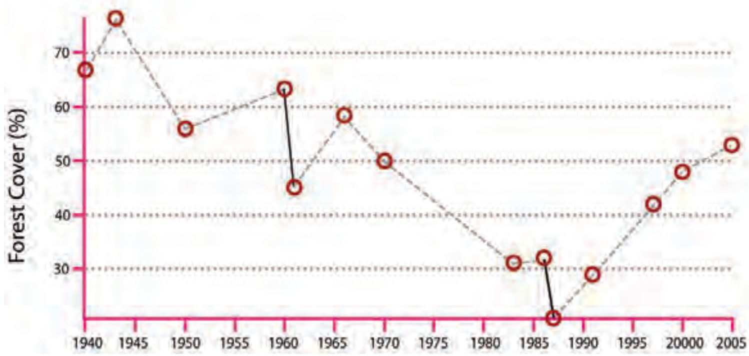
The feces contain pathogens, which is a name given to different types of viruses, protozoa, and organisms that transmit diseases such as cholera, enteric fever, paratyphoid fever, gastroenteritis, enteritis by rotavirus, diarrhea, shigellosis, and hepatitis A among others. In the developing countries the diseases caused by these pathogens are one of the most important causes of premature death, especially in children (Moreno Díaz, 2009).

8. Land Use: Deforestation and Soil Degradation

Deforestation should be a matter of great concern to any society, as it is associated with many types of devastating impacts to the environment such as: soil degradation, loss of fertile top soil through hydraulic transport, landslides, increase in extreme hydrological events (floods and droughts), reductions in aquifer recharge, loss of productivity, desertification, degradation of air quality associated with dust storms, sedimentation in rivers, loss of wildlife diversity, loss of recreational value, and loss of timber. Deforestation of tropical rain forests can have global effects on climate and on many kinds of earth life forms, as they contain approximately 25 percent of the earth's insect, plant and animal known species. These rain forests represent extremely sensitive ecosystems that are primary suppliers for much of the world's oxygen. Furthermore, the loss of the natural resources in uncontrolled deforested regions is usually not easily reversible, which ultimately result in the loss of all hopes for sustainable development, affecting the quality of life of current and future generations.

Sadly, starting around 1940 until the 1990s, Costa Rica had extremely high deforestation rates; a period when the country reduced its forest cover from more than 75% in 1943 to a historical low of only 21% around 1987 (FIG. 5). Clearing for agriculture and cattle pastures represent the largest contributors of Costa Rica rainforest destruction. The lowest point in forest cover at the end of the 1980s is part of a particularly disastrous uncontrolled deforestation epoch that started in the 1970s; a period of economic crisis when a series of related global events brought severe negative impacts to Costa Rica's economy. This created a state of depression, impoverishment, and economic disorder, and put the country in a crucial need of foreign exchange. In desperation, vast areas of rainforest were burned and converted into cattle ranches as a way to prevent economic collapse by obtaining the needed foreign exchange through the increase of beef exports to the United States (a product that at that time had an extremely high demand). In fact, earning dollars through clear cutting and deforestation became a common practice in Latin America during those difficult years (Santiago and Schmidt, 1992). When the United States ceased beef imports, Costa Rica was left with millions of acres of cleared land and a lot of cattle. The real extent of this devastation is summarized by Santiago and Schmidt, 1992: "In sum, beef exports from this nation increased nearly 500 percent from the 1960's to the late 1980's. Additionally, cattle pasture land increased from 27 percent of land mass to 54 percent of total land mass. Deforestation and pasturization of land in Costa Rica marks one the most expansive and damaging environmental disasters recorded in modern history, in terms of percentages.

" Fortunately and against all odds, Costa Rica is now one of the first countries in the world that has successfully reversed the deforestation upward trend of the past, so that the current forest cover is significantly larger than the coverage at the end of the 1980s (FIG. 5). Many diverse causes contributed to this, including external factors such as the diminishing of the international meat markets, along with internal efforts to ameliorate the dire situation at that time. More recently, one possible positive factor in the recuperation is the effect of a series of incentives for forest conservation, like the payment for environmental services (PES) program that started in 1996; which pays landowners for conserving the forest (República de Costa Rica, 1996; see also: Ortega-Pacheco et al., 2009; Redondo-Brenes and Welsh, 2006). The national PES program focus on the provision of forest services such as carbon sequestration, biodiversity protection and watershed protection (República de Costa Rica, 1996). The PES is seen by many societal sectors as a positive effort to reduce deforestation. In fact, a study has shown that several communities in Costa Rica are willing to pay higher water bills in order to implement local PES programs to protect their own water resources (Ortega-Pacheco et al., 2009). Furthermore, other factors that helped reduced deforestation rates of the past, such as the development of an environmental conscience by a larger part of the society and a change of the dependence of the country's economy toward economic activities that do not demand such large extensions of disturbed land, have also helped stop a situation that otherwise would have been catastrophic. Therefore, it should be recognized that the significant reduction of such aggressive actions against the natural resources is by itself a significant achievement, partly owed to the effort of many governmental and non-governmental organizations, and communities. Not surprisingly, however, the recuperation of forest coverage in this manner has its drawbacks. It has been found that the quality of the secondary forest is significantly below that the original forest and without a complementary enrichment process these new forests can remain relatively poor in species for decades; and that also the location of the new forests may not be optimal in ecological terms (Baltodano, 2007). A diagnostic of the characteristics of the current forests along with other criticisms can be found in Baltodano, 2007.



SOURCE: ADAPTED FROM MINAET, 2009

FIG. 5. Costa Rica Forest Cover Estimated at Selected Years (Circles) During the 1940 to 2005 Period as a Percentage of the Total Country's Area

9. Laws and Institutions Concerned with Water[1]

Costa Rica is a signer of many international treaties that define the rules for establishing sovereignty over natural resources (including water resources), as well as the protection, restoration and vigilance of them. Most of these treaties, however, are dedicated to marine resources and fewer of them address freshwater terrestrial resources (for partial list of treaties see Salazar, 1998). One example of a international treaty that concerns about the protection of all natural resources: marine and terrestrial is the "Alianza Centroamericana para el Desarrollo Sostenible (ALIDES)" or the "Central American Alliance for the Sustainable Development" subscribed by the Central American governments in 1994. ALIDES was created with the intention of creating a progressive process of change in the quality of life of the humans, which implies the economic development with social equity and the transformation of the production methods and of the consumption patterns based on ecological equilibrium. The alliance established regional compromises in 1) environmental law and natural resources, and 2) laws that regulate the evaluation of environmental impact studies, water, energy, pollution control and border development.

9.1 The Constitution of the Republic of Costa Rica

In terms of national laws related to water resources, the current (1949) Constitution of the Republic of Costa Rica, which is the fundamental base of the judiciary ordination, establish (in its article 6) the dominance of the Costa Rican Government over its territorial sea and over its exclusive economic zone in agreement with the (1973 to 1982) United Nations Convention on the Law of the Sea.

The Constitution also guarantees the right of the inhabitants to a healthy environment in its article 50: "The State will seek the greatest welfare of all inhabitants of the country, organizing and stimulating production and the fairest distribution of wealth. Everyone has the right to a healthy and ecologically balanced environment. Therefore, it is entitled to denounce any acts that violate that right and claim redress for the harm caused. The State shall guarantee, defend and preserve that right. The law determines the responsibilities and sanctions."

9.2 Organic Environmental Law

Another important environmental law is the Organic Environmental Law No. 7554 of October 4, 1995. This law defines the environment system consisting of the natural elements and their interactions and interrelationships with humans. It provides a general regulation, technical standards and principles of sustainable development. Articles 17 to 21 and 84 to 89 of this law govern Environmental Impact Assessments (EIA).

It establishes the obligation of such human activities which alter or destroy the environment or generate waste, toxic or hazardous materials, to include this type of study subject to the review of the National Environmental Technical Secretariat (SETENA

1 Most of the material from this section was obtained under permission from Salazar [1998]

in Spanish). There are guidelines that establish special requirements depending on the activity under investigation, but currently there are no specific EIA guidelines for activities carried out in coastal areas, although the law includes previsions in several articles on marine and coastal resources. In these cases general guidance is used and adapted according to the characteristics of the project.

9.3 The Water Law

The Water Law number 276 of 27 August 1942 and its amendments regulate all matters concerning the ownership, use and reuse of water within the territory. There is a differentiation of the waters of public domain and the ones of private domain. The regulation covers common and special uses of water (which are given in concession), such as public water supplies, development of hydraulic power, irrigation, navigation, nursery ponds, and other very specific uses. It also regulates natural and legal rights of way in beaches and maritime zones (but these areas also have special law).

The waters in the public domain under the Water Act are: seas or territorial waters in the extent and terms set by the International Law, lagoons and estuaries or beaches that communicate constantly with the sea; or rivers and their direct or indirect tributaries, streams or springs, from their original springs in the headwaters down to their outflow in estuaries, lakes, lagoons, and seas. In addition, it includes beaches and maritime zones, lakes, lagoons and estuaries of national ownership, the reclaimed land to the sea by natural causes or by artificial works, among others. The Water Law also establishes that rainfall that falls on the premises of a landowner is considered private water, and belongs to that landowner as long as the water runs through the property. The same applies for any gaps or puddles formed in the respective domain land, groundwater obtained from the owner in its own ground through wells, as well as thermal, medicinal and mineral water whatever the place they erupt.

Invalidating the rules specified in the preceding paragraph, the enactment of the Mining Code in 1982 impliedly repealed the distinction between private waters and public waters, maintaining the public character of all waters. In the Mining Code, the Article 4 stipulates that the sources, groundwater and surface water, are reserved to the State and may only be exploited by it, or through a concession especially given for a limited time and under the conditions and stipulations set by the Legislature in addition to other resources. When companies or industries either public or private have interest of exploiting water resources in a special way, it should be made through a concession granted by the Ministry of Environment and Energy (MINAE), the entity responsible to establish and deciding on the domain of public waters, except in regard to drinking water, as the construction of pipelines for public use is under the responsibilities of the Ministry of Health.

Every aspect related to concessions is regulated in Articles 17 to 29 of the law. With regard to the competent organ, the MINAE exercise dominion and control of public waters in order to grant or deny licenses and permits for their exploitation. So MINAE is the body responsible for implementing this law.

The Water Law is more than fifty years old, which suggests that it's outdated and unable to address modern circumstances and problems. Salazar (1998) mentions some of the problems of this law: 1) The law was issued primarily to regulate water use by private persons, a figure was not provided for the allocation of water to public entities, 2) the law has a high degree of detail that should be delegated to a regulation, 3) the law has not been updated with some concepts for planning, resource use and recovery, which may be deduced from the general obligations, but should be explicitly identified, 4) some of the rules are not effective or efficient, 5) despite the regulations, the protection of water resources is not guaranteed because the law has no mandatory rules for the implementation of decisions, or sanctions of sufficient severity to ensure compliance, 6) after this law have been issued, other laws have reduced the powers of the Water Law to some extent, which complicates the administration because they are not always clearly defined competencies, and 7) The Water Law does not have appropriate mechanisms for resolving conflicts over water use.

9.4 General Health Law

Water is considered by the General Health Law 5395 and its amendments, as a good of public purpose and its use for human consumption has priority over any other use. The General Health Law provides that it is the State's responsibility to ensure the overall health of the population. Also, the Executive branch of the Government through the Ministry of Public Health has the obligation of defining the national health policy, planning and coordination of all public and private activities related to health, and the implementation of those activities within its competence according to law. The Ministry has powers to create regulations in this area.

The Health Law defines as potable water, the one that meets the physical, chemical and biological properties that make it suitable for human consumption according to the drinking water norms of the Panamerican Health Organization approved by the Government.

Any water supply system for use and consumption of the population must provide potable water on a continuous basis, sufficient to meet the needs of people, and pressure necessary for the proper functioning of medical devices in use. All homes individual, family or multifamily must meet health requirements such as having adequate systems for sewage disposal and storm disposal approved by the Ministry of Health. Any natural or legal person is obliged to contribute to the promotion and maintenance of environmental conditions, (being natural and artificial) that allow fulfillment of the vital needs and health of the population (Article 262). Moreover, actions, practice or operations that deteriorate the natural environment are prohibited, along with those that change the composition or intrinsic characteristics of its basic elements, especially air, water and soil; producing a decline in their quality or aesthetics, or that make such commodities useless for some of the uses to which they are intended, or produce problems to human health, or to the flora and fauna harmless to human beings (Article 263).

Everyone is obliged to implement the actions, practices or works provided by law or regulations to eliminate or control the elements and natural environmental factors, physical or biological and from the artificial environment, that are harmful to human health.

It is prohibited for any natural or legal person to contaminate surface water, groundwater and maritime territorial waters, directly or indirectly, through drainage or discharge or storage, through intentional or negligent waste disposal of liquid waste, solid or gaseous waste, radioactive or nonradioactive, sewage, or substances of any nature that through altering physical, chemical and biological characteristics of water make it dangerous for the health of humans and terrestrial and aquatic wildlife or unusable for domestic, agricultural, industrial or collection uses (Article 275).

Only with permission of the Ministry of Health natural or legal persons can make a drainage or discharge residual waste (solids or liquids), or any other contaminants into surface water, groundwater or maritime water; and they should adhere strictly to safety rules and regulations and special procedures that the Ministry may impose in each particular case to render them harmless (Article 276).

9.5 Forestry Law

The Forestry Law number 7575 of February 13, 1996 regulates the patrimonial State forests and the private activities that might affect it. In this Law, protection areas close to rivers are identified, and also it mentions that the State has an obligation to ensure the protection of watersheds.

The Ministry of Environment is in charge of the regulation of this law, through the National System of Conservation Areas. The Forestry Law generally seeks to establish regulations that limit the right of free use of private property in order to assert a environmental public interest to benefit the most people; as maintaining forest, soils, water and air, also results in improvements to the quality of life of the population. Any disruption in the ecological balance between soil, forest and water results in a clear deterioration in the quality of life for humans.

All land with forestry potential and all forests in the country, whether owned by the State or reduced to private ownership, are subject to the Forest Law for enforcement purposes. The Forestry Law defines the forest regime as a set of legal, economic and technical provisions established by law and its regulations, along with other rules and acts arising from their application, with the objective to regulate the conservation, protection, restoration, use and development of forest resources.

The following locations are considered protected areas: a) the areas that border permanent springs, defined en a 100 meters horizontal radius, b) a 15 meters strip in rural settings and 10 meters in urban settings measured from both sides of river banks, creeks or streams if the terrain is flat, and a 50 meters strip if is uneven, c) a zone of 50 meters measured horizontally from the river banks of lakes and natural or artificial reservoirs built by the State and its institutions, d) the recharge areas and the spring aquifers, with borders defined by the institutions established en the Regulations of this law.

10. Integrated Water Resources Managing and Planning

Integrated water resources managing and planning is the only way to guarantee sustainability, ecosystem health, mitigation against climate-induced disasters, and environmental protection. Some of the tools for reaching such objectives are the introduction of a systematic approach and the concepts of adaptive management. This effort will require the unprecedented coordination and collaboration of many institutions and people, including physical and social scientists, specialists and technicians in many fields, stake holders, decision-makers, administrators, private and public organizations, local governments and community organizations.

A better understanding of climate variability and change in the region is one of the basic parts of this approach, as the availability of water could have large year-to-year variability, even from natural variations alone. In addition, anthropogenic climate change may impose new challenges to the availability of water resources and could add pressure on the ecosystems of the region.

Many valuable studies have been developed in the past (i.e. Amador et al., 2000; 2003; Fernández et al., 1996; George et al.,1998, IMN, 2009). Among many other discoveries, these studies have shown than some of the most significant features that influences climate of the region are (in no particular order): 1) El Niño Southern Oscillation strong influence (George et al., 1998; Amador et al., 2000), 2) The tropical storms and hurricane influence, 3) The Midsummer Drought (Magaña et al., 1999), 4) The influence of the Low-level Jet (LLJ) and 5) the latitudinal displacements of the Intertropical Convergence Zone. The interaction of these features with the diverse topographic features in the country, produce large spatial and temporal variability at diverse time scales, in particular in precipitation.

In terms of climate change, IMN, 2009 study suggest an even drier and warmer future in the already climatologically dry North Pacific (Guanacaste), a region with considerable areas devoted to agricultural and cattle ranching activities, and that has had an impressive increment of tourism over the past 15 years. The study also contains estimations of the impacts on different sectors, along with possible adaptation strategies. However, future studies should be based on the projections from more climate models and the downscaling model may need to be revised.

There is however, much to be done in order to integrate previous research along with new studies into a comprehensive body of knowledge to support water resource operations, management and planning. Also, more studies are needed to evaluate the impacts of climate, meteorology and hydrology in several sectors such as flood and drought mitigation, agriculture, socioeconomics, ecology, water quality, hydropower generation, public health and others.

It is proposed here that the creation of a system-of-systems (SS) for each basin could be a way to address the complexity of this kind of problems. The SS will be based on a communication system, but also includes users (including community leaders) and managers of the system, along with other support personnel. As an example, the first level of the SS could consist of coupled meteorological-hydrological short range or seasonal forecast. This first system would feed a particular impacts system, such as an agricultural production model. A real additional value would be added to the SS if it contains another system to provide concrete recommendations to the end users and decision makers on what to do.

This would be done through decision support systems (DSS). Examples of DSSs could be 1) one that provides information about the best crop to grow for each particular year (crop rotations), 2) one that suggests adjustments to the primes of crop insurances for different crops, 3) one that calculates the amount of imported water and grass that will be needed to support cattle at each particular year, 4) regions with a greater probability of experiencing water supply problems, and others. Similar DSSs could be done for planning (taking into consideration climate change and sustainability) and another one could be designed for disaster prevention or mitigation.

An example of this latter type of DSS is currently in operation in the National Meteorological Institute (IMN in Spanish), called the Central America Flash Flood Guidance (CAFFG) system, which was developed by the Hydrologic Research Center in San Diego. The CAFFG is a flash flood early warning system, and consists of a hydrological model that is fed using rainfall forecasts based on data from satellite and surface meteorological stations. The hydrological response is later interpreted in terms of warnings of different types, such that the meteorologist or hydrologist in each Central American country can have better criteria whether evacuation is justified.

Another example of a system that could potentially be used for supporting some decisions is the SERVIR (Latin America) system (http://www.servir.net/america-latina-caribe) , which is a centralized repository of all kind of information about natural disasters in Latin America and the Caribbean, including some meteorological and hydrological forecasts. SERVIR, however, does not provide information about the possible impacts of the hydrological forecast on different sectors or specific suggestions to decision makers about what to do with this information.

11. Conclusions

Costa Rica is a country of great contrasts regarding the use and conservation of water resources, the ecosystems and the environment. Over the last 15 to 20 years, there has been an increasing concern for conserving the forests, soils and natural resources that has been recognized internationally. However, many serious environmental problems from the past still remain. Among all kinds of over-exploitation and water quality problems in terrestrial, coastal and marine environments, perhaps one the gravest is the severe contamination of urban streams and aquifers, mainly associated with the lack of adequate sanitation facilities and the uncontrolled growth of these areas. Cleaning the country’s land and water in these settings represents a significant challenge that will need the continuous efforts of many sectors of society for several years to come.

On average, Costa Rica only uses a very small percentage of its available water, which may erroneously give the impression that there is an immense amount of water everywhere that could potentially be further exploited for human consumption. However, when the necessities of water for many uses including the sustainability of natural resources that would provide ecosystem services to support adequate socioeconomic development are considered, it is entirely possible that in some regions, "water scarcity" and over-exploitation is or will be a reality in the near future under the current characteristics and management of the system.

Optimizing water resources management and planning could help increase the amount of safe exploitation of water for domestic, agricultural or industrial use, but more and better integrated studies and projects are needed to be developed to determine this.

Developing integrated watershed studies that feed decision support systems, for water management, water planning and climate-induced disaster preparedness and mitigation, along with other related actions such as the development of an enforceable territorial ordination plan can help save lives, guarantee sustainability, protect and reduce the impact of human activities on natural resources and ecosystems, reduce socioeconomic impact of climate variability, help optimization of limited economic and human resources, help adaptation to climate change, help to prepare for extreme hydrological (floods and droughts) and protect vital infrastructure. Such systems are necessary due to the complexity of integrated managing and planning for water resources, especially in Costa Rica, where laws and institutional framework governing water resources management are sometimes inadequate for addressing modern problems.

This adds new challenges to the organization of a consensual integrated solution of problems. In addition, the benefits for society of these systems surpass by far the implementation and operation costs. More economic studies are needed to evaluate not only the benefits and costs of implementation, but also the no-action costs to society. This will help securing funds and establishing priorities under limited budgets.

Even that hydrology is an applied science, there seems to be a need for a better connection of a large part of academic, governmental institutions and industry research with stake-holders (government, decision makers, local governments, non-governmental organizations and the community). This is even a challenge in some other regions of the world that have more economic resources (and are generally better organized) than Costa Rica. Therefore this limitation actually stresses the importance of optimizing the transference of (hydro) climatic information and knowledge obtained through the academia, the government and the industry's research into concrete benefits to the society in developing countries.

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13. References

1. Amador, J. A., R. E. Chacon, and S. Laporte (2000), Cuenca del Río Arenal: Análisis de los eventos La Niña de los años 1988-89 y 1996, Tópicos meteorológicos y oceanográficos, 7, 50-62.
2. Amador, J. A., R. E. Chacon, and S. Laporte (2003), Climate and Climate Variability in the Arenal River Basin of Costa Rica, Climate and Water, Transboundary Challenges in the Americas, H.F. Diaz and B.J. Morehouse eds., Kluwer Academic Publishers, Netherlands, 317-349.
3. AyA (2007), Plan Estratégico Institucional 2007-2015, Instituto Costarricense de Acueductos y Alcantarillados, San José, Costa Rica, 65 pp.
4. Baltodano, J. (2007), Decimotercer informe Estado de la Nación en desarrollo humano sostenible, bosque, cobertura y uso forestal, Programa Estado de La Nación, 59 pp.
5. Chaves, C. (2009), Casi listo tratamiento de aguas en San José, Costa Rica Hoy online newspaper, (Aug 28 2009 edition), San José, Costa Rica. <http://costaricahoy.info>, Accessed: Jan 1st, 2010.
6. CIA (2009), The World Factbook, United States Central Intelligence Agency, United States. <https://www.cia.gov/library/publications/the-world-factbook/geos/cs.html>, Accessed: Jan 1st, 2010.
7. COMEX (2008), Evolución del PIB nominal 1991-2008, Ministerio de Comercio Exterior de Costa Rica, San José, Costa Rica, 1 pp.<http://www.comex.go.cr/Paginas/inicio.aspx>, Accessed: Jan 1st, 2010.
8. Fernández-González, A., and E. Gutiérrez-Espeleta (2002), Freshwater in Costa Rica: abundant yet constrained, In: Human Security and the Environment. International Comparisons, E.A. Page and M. Redclif, eds, Edward Elgar Publishing Limited, Northampton, United Kingdom, Massachusetts, United States, 267-284.
9. Fernández, W., R. E. Chacon, and J.W. Megarejo (1996), On the rainfall distribution with altitude in Costa Rica, Revista Geofísica, 44, 57-72.
10. George, R., Peter R Waylen, and S. Laporte (1998), Interannual Variability of annual streamflow and the Southern Oscillation in Costa Rica, Hydrological Sciences Journal, 43, 409-424.
11. IMN (1985), Atlas climatológico (1961-1980), Instituto Meteorológico Nacional de Costa Rica, San José, Costa Rica. <http://www.imn.ac.cr/mapa_clima/

altas_clima/atlas%20clima.html>, Accessed: Jan 1st, 2010.
12. IMN (2009), Segunda comunicación nacional ante la Convención Marco de Cambio Climático, Instituto Meteorológico Nacional de Costa Rica, San José, Costa Rica, 264 pp.<http://cglobal.imn.ac.cr/comunicacion.asp>, Accessed: Feb 28th, 2010.
13. INEC (2004), Geografía y clima, Instituto Nacional de Estadística y Censos de Costa Rica, San José, Costa Rica, 2 pp.<http://www.inec.go.cr/>, Accessed: Jan 1st, 2010.
14. INEC (2008), Boletín Anual, Indicadores Demográficos 2008, Instituto Nacional de Estadística y Censos de Costa Rica, San José, Costa Rica, 2 pp.<http://www.inec.go.cr/>, Accessed: Jan 1st, 2010.
15. Magaña, V., J. A. Amador, and S. Medina (1999), The Midsummer Drought over Mexico and Central America, Journal of Climate, 1577-1588.
16. MINAE, and IMN (2007), Adaptación del sistema hídrico de la zona noroccidental de la Gran Área Metropolitana de Costa Rica al cambio climático, informe final, Ministerio de Ambiente y Energía e Instituto Meteorológico Nacional de Costa Rica, San José, Costa Rica, 50 pp.
17. MINAET (2009), Avance Formulación R-PP para Costa Rica, Ministerio de Ambiente, Energía y Telecomunicaciones, 24 pp.
18. Ministerio de Salud, and Organización Panamericana de la Salud (2003), Calidad del agua potable en Costa Rica, situación actual y perspectivas, 13th ed., Por: Ministerio de Salud de Costa Rica, Instituto Costarricense de Acueductos y Alcantarillados, Organización Panamericana de la Salud, y Oficina Regional de la Organización Mundial de la Salud, 36 pp.
19. MIVAH, MINAE, and PNUMA (2006), Perspectivas del Medio Ambiente Urbano, Geo Gran Área Metropolitana Valle Central, Costa Rica, Ministerio de Vivienda y Asentamientos Urbanos, Ministerio del Ambiente y Energía y Programa de las Naciones Unidas para el Medio Ambiente bajo la coordinación técnica del Observatorio del Desarrollo de la Universidad de Costa Rica, San José, Costa Rica, 268 pp.
20. Monge Flores, Esteban (2009), Agua y producción, Centro Ecuatoriano de Derecho Ambiental, Quito, Ecuador, 33 pp.<http://www.ceda.org.ec/descargas/biblioteca/Agua%20y%20Produccion.pdf>, Accessed: Jan 1st, 2010.
21. Moreno Díaz, M.L. (2009), Valoración económica del uso de tecnologías de saneamiento ecológico para aguas residuales domiciliares, Revista Iberoamericana De Economía Ecológica, 13, 1-13.
22. OD (2001), Boletín del Observatorio del Desarrollo de la Universidad de Costa Rica, Observatorio del Desarrollo, Universidad de Costa Rica, San José, Costa Rica, 8 pp.
23. Ortega-Pacheco, D.V., F. Lupi, and M.D. Kaplowitz (2009), Payment for Environmental Services: Estimating Demand within a Local Watershed,

Journal of Natural Resources Policy Research, 1, 189-202.
24. Peter H. Gleick and associates (2008), The World's Water 2008-2009, Island Press, Washington DC, United States.
25. Programa Estado de la Nación (2009), Decimoquinto Informe Estado de la Nación en Desarrollo Humano Sostenible, 2009th ed., Programa Estado de La Nación, San José, Costa Rica, 64 pp.<www.estadonacion.or.cr>, Consulado: Jan 1st, 2010.
26. Redondo-Brenes, A., and K. Welsh (2006), Payment for hydrological environmental services in Costa Rica: The Procuencas case study, Tropical Resources Bulletin, 24, 19-25.
27. República de Costa Rica (1996), Ley Forestal, Asamblea Legislativa, San José, Costa Rica.
28. Salazar, R. (1998), Marco Jurídico y Administrativo de las Aguas en Costa Rica, Sistema Nacional para el Desarrollo Sostenible, Ministerio de la Presidencia y Planificación de Costa Rica, San José, Costa Rica. <http://www.mideplan.go.cr/sinades/Proyecto_SINADES/sostenibilidad/armonizacion/index-6.html#_Toc429478972>, Accessed: Jan 1st, 2010.
29. Santiago, A., and J.A. Schmidt (1992), Costa Rica Hamburgers, TED Case Studies, 2. <http://www1.american.edu/TED/class/all.htm>, Accessed: Jan 1st, 2010.
30. Tribunal Latinoamericano del Agua (2008), Foro: "Sistemas Hídricos en Guanacaste: Sustenabilidad o Desastre", Guanacaste, Costa Rica, DOI: XXXX, ISSN:XXXX.<www.tragua.com>, Accessed: Jan 1st, 2010.
31. UN (2006), Water, a shared responsibility, The United Nations World Water Development Report 2, UNESCO and Berghahn Books publishers, New York, United States, 601 pp.
32. UNA (2004), La situación del agua en Costa Rica (resumen ejecutivo), Universidad Nacional de Costa Rica, Heredia, Costa Rica, 20 pp.<http://www.una.ac.cr/campus/ediciones/otros/agua>, Accessed: Jan 1st, 2010.
33. UNEP (2003), GEO Latin America and the Caribbean - 2003, United Nations Environmental Program and Observatorio del Desarrrollo, Universidad de Costa Rica, San José, Costa Rica, 279 pp.
34. UNESCO (2007), Balance hídrico superficial de Costa Rica Período 1970-2002, Programa Hidrológico Internacional de la UNESCO para América Latina y el Caribe (phi-LAC), San José, Costa Rica, 55 pp.
35. Vargas Sanabria, A. (2003), El manejo de los recursos hídricos en Costa Rica durante los siglos XVIII y XIX, Ciencia y Técnica en la Costa Rica del Siglo XIX, G. Peraldo Huertas compilador, Editorial Tecnológica de Costa Rica, San José, Costa Rica, 376-401.


Morro Castle, Santiago de Cuba

Water Resources in Cuba
An Overview

Editors
Ing. Pedro Luis Dorticós del Río[1], Dra. Ing. Mercedes Arellano Acosta[2], Dr. Jorge Mario García Fernández[3]

Authors
Margarita Fontova de los Reyes[3], Nercy Becerra Infante[3], Eulalia López Álvarez[3], Argelio Fernández Richelme[3], Enrique Martínez Ovide[3], Abel Fernández Díaz[3], Rubén Hernández Boy[3], María Isabel González González[4], Leyda Oquendo Barrios[5], Carmen Terry Berro[5], Rigoberto Lamyser Castellanos[6]

[1]Unión Nacional de Arquitectos e Ingenieros de la Construcción de Cuba

[2]Comisión del Agua, Academia de Ciencias de Cuba

[3]Instituto Nacional de Recursos Hidráulicos

[4]Instituto Nacional de Higiene y Epidemiología

[5]Archivo Nacional (Ministerio de Ciencia, Tecnología y Medio Ambiente, CITMA)

[6]Ministerio Industria Básica

1. Introduction

At the triumph of Cuban Revolution, in 1959, reservoir capacity in the country was only 48 million of m^3, distributed in 13 reservoirs. Since the early 1960's, the effort known as "Hydraulic Will" was a coherent governmental response to guarantee water supply, in adequate quantity and quality, for economic and social development, as well as environmental protection in the country. It was as a reaction to the occurrence of extreme events, in 1961-1962 (intensive drought) and 1963 ("Flora" Hurricane, which caused more than 1,000 deaths only in the eastern region of the main island).

There are some facts that determine the actions related to Cuban hydraulic development, to the guaranteed water supply with proper quantity and quality, and to the integrated management of water resources /1/. Among them: 1) vulnerability due to the archipelago natural conditions: Cuba is an insular state; 2) central watershed along the main island that defines the formation of numerous small surface basins and, at the same time, the predominance of karst in underground aquifer formations; 3) dependence of our water resources on the behavior of annual rainfalls; 4) climatic variability that is reflected in different ways, such as the change in rainfall regime; 5) eminently agricultural development, according to the water resource use structure; and 6) Climate change and the adaptation and mitigation measures.

The hydraulic resources potential for economic, social and environmental appear in FIG. 1. This infrastructure includes 239 reservoirs that store close to 9,000 hm^3 and are able to deliver more than 7,000 hm^3, 730 small reservoirs (less than 3 hm^3), 12 big pumping stations, 1,212 km of dikes and 1,082 km of protection works against floods, and 760 km

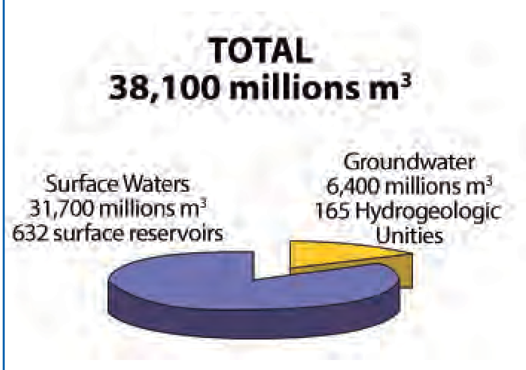


FIG. 1 Potential Hydraulic Resource

of main canals. The total water and hydraulic resources in the country are summarized in FIG. 1 and Table 1 summarizes the water resource availability indicators. As is shown in table 1, the national Classic Availability Indicator reaches 1,220 m^3/inhab/year, approximately, for all uses.

This same Indicator, as regards Potential Hydraulic Resource, is 3,400 m^3/inhab/year, and with respect to Exploitable Hydraulic Resources, is 2,140 m^3/inhab/year.

The classification places these values among those of low availability per capita (between

Table 1. Classic Water Resource Availability Indicator[1]

Classic Water Resource Availability Indicator	m^3/inhab./year	Classification
Regarding Potential Water Resources	3,400	Low
Regarding Exploitable Water Resources	2,140	Low
Regarding Available Water Resources	1,220	Low
Water Stress Indicator (WSI, %): It gives an idea of the balance between water uses and water resources (volume). Values higher than 40 % are estimated as High or Very High Water Stress. Efficiency elements as regards water uses and consumption patterns are not considered.		
WSI % = (Water Uses/Water Resources) x 100	(%)	Stress, classification
Regarding Potential Water Resources	18	Low
Regarding Exploitable Water Resources	29	Medium
Regarding Available Water Resources	51 44 36	High (7 km^3) High (6 km^3) Medium (5 km^3)

1,000 and 5,000 m^3/inhab/year), for any selected resources in indicator assessments (potential or exploitable). However, specialized bibliography has recognized that this indicator is more a reflection of water relative richness, starting from its main natural sources –rainfalls, in Cuban case–, than the own hydraulic development of a country.

In Cuban case, this is evidenced through the results reached in the last Study on Rainfalls in Cuba (2006) that determines a mean national rain depth of 1,335 mm.

Recent researches applying the "Water Footprint" Indicator[2] are putting Cuba in place 30 among a group of 142 countries, with values of 1,712 m^3/inhab/year.

2. Water Uses. Assigned Percentages for each Use

Hydraulic resources planning in Cuba is established on legal bases (Legislation Chapter), and has its punctual expression in each surface source, reservoir or non regulated flow, in each well, and in each underground basin, for each user, both for irrigation and for supply to population, industry and cattle raising. It includes ecological needs.

Different water uses in Cuba are not competitive among them.

The system for annual planning respects established priorities, where population supply occupies the first place. Distribution and integral management of assigned volumes includes the joint use of surface and groundwater. FIG. 2 shows the water volume planned in 2009.

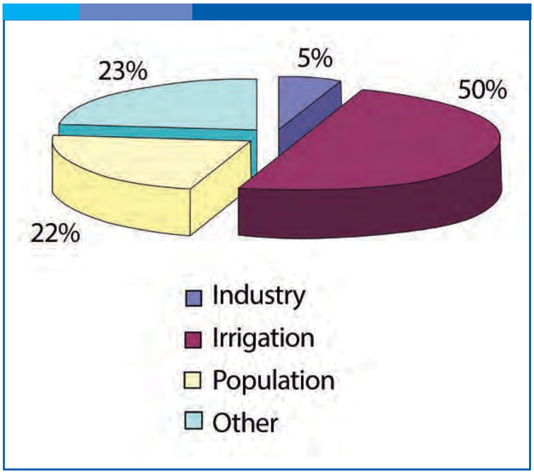


FIG. 2 Hydraulic Resources planned to be used in 2009 [3]

3. Water and Agriculture

The area with agricultural purposes, in Cuba, is 6,619.5 thousand hectares (Tha). By the end of 2007, cultivated surface was 2,988.5 Tha; of which, 60.1 % are remaining crops and 39.7 % temporary crops. Sugar cane occupies 1,141.1. Of the non cultivated agricultural area, 2,398.2 Tha correspond to natural grazing land.

Up to 1959, irrigation had been developed in small lots, concentrated close to rivers or with sufficient groundwater availability. The total area under irrigation existing in that period was 160 Tha, which benefited crops like rice, sugar cane, potato, and other vegetables. Irrigation technologies were obsolete, and almost all the land was irrigated using very rudimentary superficial methods. Scarce existing irrigation systems by aspersion were portable equipment, belonging to some farmers with higher economic possibilities. Water reservoir volume, in these years, did not reach 50 million m^3 and was used for population supply and sugar cane irrigation, mainly. As a result of the "Hydraulic Will" effort, a wide construction program was developed in the hydraulic sector in an accelerated fashion. With the goal of increasing food productions for population consumption and the technological development in agriculture, an irrigation system construction program was implemented.

It made possible an increase in irrigation area from 160 thousand hectares, by the end of the 1950's, to near one million hectares at the end of 1989.

In the 1990's, there was a strong impact of economic declination on agricultural development, strengthened by the economic blockade from US government, together with changes in Cuban commercial conditions and affairs with Eastern European countries. There was an important decline in irrigation areas; therefore, in 2000 these areas were only 553.1 thousand hectares (73% with respect to 1983).

Higher impacts were produced in sugar cane irrigation and cultivable graze lands, with a reduction of 227.0 thousand hectares and 72.8 thousand hectares, respectively. However, an increase of 60 thousand hectares occurred in irrigation areas devoted to produce vegetables and beans. Dynamics of irrigation areas from 1959 to 2009 is shown in FIG. 3.

At the end of 2009, irrigation areas reached 500 thousand hectares approximately; 15.9% of which are irrigated by aspersion techniques; 5.3%, with machinery; 6.3% by

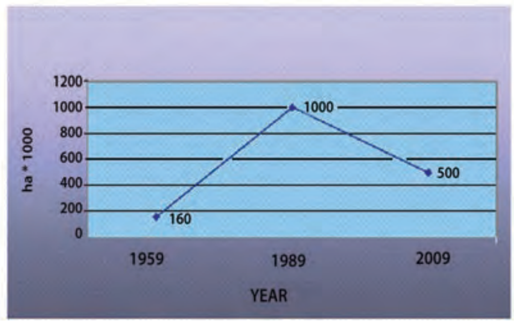


FIG. 3 Dynamic water under irrigation

local irrigation techniques; 60.9% by gravity, and 1.5% by other techniques. Gravity irrigation techniques have been the most commonly used and the least efficient (4).

From the water volume planned for all uses in the country, 50.0% is devoted to irrigation. Rice is the crop of higher demand (38.9 % of the volume planned for irrigation and 21.0% of the volume planned at national level).

The current and prospective program for main crops is based on a reduction of the continuing deterioration of irrigation systems, and irrigation areas in general, with the purpose of maintaining the current areas in optimal conditions, with a view to increase irrigation productivity and water use efficiency. The main actions are summarized as follows:

a) Beginning the Electrification of Irrigation Systems: It reached 160 thousand hectares in 2008.

b) Introduction of science and technological innovation results: Research centers related to the irrigation sector are presently working on:

- Search for seed varieties more resistant to external factors, and with lower water requirements;
- Application of technological solutions (shows evident results at present in crops like potatoes, with higher productivity and efficiency in water use).

c) Development of national industry to increase the use of irrigation techniques: as a way to increase its productivity.

d) Increase in agriculture production, starting from deep transformations in its structure: decentralization of production: from bigger enterprises to other ways of individual or collective production, such as small enterprises, cooperative production and others, depending on crop type and available resources, aiming at an increase in agriculture production.

Nowadays, Cuba produces the elements for irrigation systems, both punctual and using machinery, even with the existing limitations as regards financial resources and market access.

Development of "Organoponics" (or popular vegetable gardens using organic fertilizers)

Their development began in 1994, mainly for vegetable production, by means of a popular movement for urban agriculture.

For their own interest, a great number of persons and families have been incorporated, to produce food in each available square meter in cities, towns and other settlements, under the principle of sustainable agriculture. In these "organoponics", vegetable gardens and small plots, by the end of 2009 it was reached 15088 ha under irrigation: 45.2 % with aspersion technique, 16.7% by gravity, 10.6% punctual and 27.3% by using other techniques. Nearly 177.7 ha are located in crops houses.

4. Water and Industry

In Cuba industry demands great volumes of water and, at the same time, produces effluents whose management, in many cases, affects the quality of this vital resource. Cuban industries are supplied in two ways: exploiting water sources administrated by themselves, or through municipal or local aqueduct systems. In both cases, they have the legal obligation of paying a fee, as well as for the sewerage service if provided. An additional tax must be paid if the assigned consumption is exceeded, which varies according to the users, territories or watersheds, depending on water balances and the economical and social needs.

During the period 2002 -2009 were executed assessments with cleaner production (CP) approach, in plant and in several industries. The results obtained with respect to their performance, as regards water management, as successful cases studies of CP strategies application, in Table 2 are shown.

These benefits were obtained by applying measures such as: training of workers; installation of water flow meter; improve in cleaning system; substitution of freezing system; recovery of condensed water, and waste water reuse. In spite of these goals reached, cleaner production practices, and its application in the Cuban industry is insufficient.

Table 2. In Selected Industries: CP Approach Application. Results of Plant Assessments

		Food industry	Biotechnology industry	Sugar cane agro-industry	Fruit agro-industry	Total
Water consumption reduction	Environmental benefits (m^3 of saved water)	2 277 000	173 850	2 720 505	469 774	5 652 495
	Economic benefits (USD)	683 100	173 850	811 453	131 650	2 426 683
Polluting load reduction (t COD)		18 280	44	42 133	5 055	65 589

COD: Chemical Oxygen Demand. Source: National Cleaner Production Network, 2007[4]

At present, all the stakeholders endeavor to achieve a sustainable water management in Cuban industry and agro-industry, through the promotion of measures such as: 1) integration of water management to the industry's economic management; 2) environmental education and training of the personnel; 3) installation of flow meters in industries with higher water consumption, prioritizing highest users; 4) determination of national and sector consumption indexes, taking into account the peculiarities of each industry; its comparison with similar foreign enterprise , 5) effective application of the environmental management instruments existing in the country (environmental legislation; system of environmental recognitions and certifications; System for Enterprise Direction and Management), to improve national industry performance, related to water management.

5. Water for Human Consumption. Quantity, Quality and Access

The Cuban State guarantees the development of potable water and sanitation systems, through a National Action Program executed by the Instituto Nacional de Recursos Hidráulicos, INRH. This allows increasing water access cover to all sectors of economy and society. At the end of 2008, population access to potable water was 92.4%, with the structure shown in FIG. 4, with a total of 2,253 aqueducts.

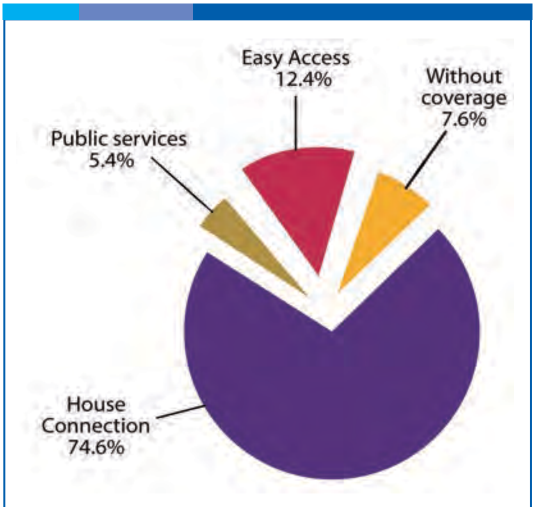


FIG.4 Water Supply Coverage 2008

Selected indicators appear in Table 3, for urban and rural sectors, corresponding to the period 2000-2008, and FIG. 5 shows the dynamic of potable water supply cover by sectors (urban, rural) from 2000 to 2008. Water Quality Indicators respects to chlorination (%), at level of country, in 2008 were: continuity

Table 3 Selected Indicators of Water Supply Cover by Sectors

Indicator	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total Population Served	90,3	91,1	91,2	91,2	91,6	91,6	92,1	92,4	92,4
House Connection (%)	71,1	71,9	73,4	73,4	73,2	73,2	74,4	74,6	74,6
Public Service (%)	7,4	6,2	5,7	5,7	5,8	5,8	6,4	5,4	5,4
Easy Access (%)	11,8	13,1	12,1	12,1	12,6	12,6	11,3	12,4	12,4
Urban Sector (%)	96,3	96,4	96,5	96,5	96,3	96,3	96,8	96,9	96,9
House Connection (%)	82,4	83,1	84,8	84,8	84,9	84,9	86,7	86,9	86,9
Public Service (%)	5,1	4,4	3,4	3,4	3,5	3,5	3,6	3,4	3,4
Easy Access (%)	8,8	8,9	8,3	8,3	7,9	7,9	6,6	6,6	6,6
Rural Sector (%)	72,2	75,3	75,5	75,5	77,3	77,2	77,7	78,3	78,3
House Connection (%)	35,8	36,8	38,0	38,0	37,0	37,0	36,5	36,8	36,8
Public Service (%)	15,4	12,2	13,1	13,1	13,0	13,0	14,8	11,5	11,5
Easy Access (%)	21,0	26,3	24,4	24,4	27,3	27,2	26,4	30,0	30,0

Source: INRH Statistics, 2008

of chlorination: 98.4%; treatment percent of served water to treat: 97.2 %; Bacteriological Potability Index: 94.9 %.

Taking into account the incidence of these activities on health and quality of life of rural and urban population, since last century's final decades a National Action Plan was identified and is being developed, closely related to existing commitments to accomplish the Millennium Goals as regards water and sanitation issues. A summary of the analysis carried out in relation to these goals, for the period 2000-2005, appears in Table 4.

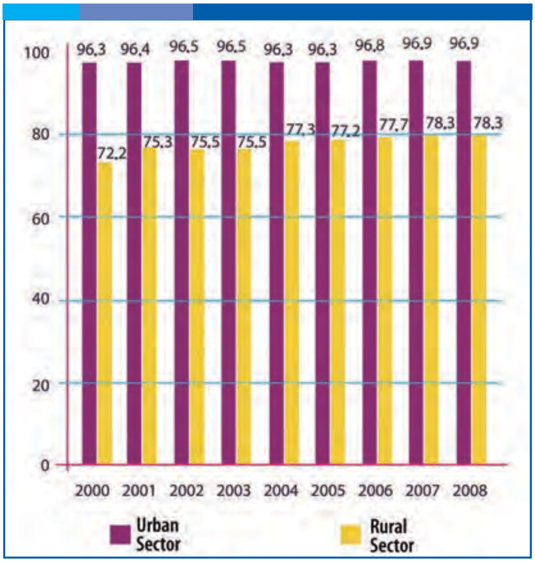


FIG. 5. Water Supply by Sectors. Coverage 2000-2008

Table 4. Water and Sanitation with Respect to Millennium Goals 1990-2008

Cuba	Benefit Population 1990-2008 (inhabitant)	Fulfillment %	Without Coverage (2008)
Fresh Water	1,102,605	112.4	859,230.00
Sanitation	734,686	122.0	470,137.00

6. Terrestrial Waters Quality

About 67% of Cuban territory is constituted by carbonated rock complexes. To a great extent, these rocks are karstified and with a high aqueousness degree (between 10-300 l/s). An 11% of karstified rocks, aquifers also, present a variable aqueousness between 1-

10 l/s. Volcanogenic rock complex comprises approximately 15%, with a low aqueousness of 1 l/s; and 5,9% corresponds to ultra basic rocks, with a medium aqueousness, having different discharge values of up to 1 l/s. In weathering areas, they reach up to 5 - 10 l/s, or more, frequently in fracture zones. Aquifers in Cuba are mostly constituted by calcite and dolomites, or dolomitic calcite. Salt content in theses rocks is dissolved in water, by virtue of all the processes of water-rock interaction and the hydrologic cycle.

The island condition of the territory determines the permanent interaction of terrestrial and coastal and marine waters. This balance may be affected due to anthropogenic causes, thus causing an increase in the contents of chlorides, sodium and other salts in terrestrial surface and ground waters. In the case of groundwater, seawater intrusion in aquifers, especially in karstic ones, constitutes an ever-present issue, considering hydraulic ratios established between fresh- and seawater. In equilibrium conditions, terrestrial waters have a saline content lower than 500 mg/l, with higher values at river mouths and in estuarine areas. In those ground basins whose waters are in direct relation to the sea, depending on their management and administration, water characteristics may vary from calcium bicarbonate or magnesic to sodium-chloric or sodium bicarbonate-chloric. Their salinity values increase up to figures higher than 1 g/l of Total Dissolved Solid, thus becoming unsuitable for crop irrigation, human consumption, and other uses.

As for physical properties, color and turbidity of Cuban surface waters vary according to the seasonal period (rainy, less rainy). In general, surface water flow and bodies present saturation dissolved oxygen content close to 100%, at temperatures between 20 and 28 oC. These values fluctuate depending on the seasonal period, as well as on the characteristics of the up-stream basin, where various phenomena like erosion can cause higher values of suspended solid transport.

Surface and ground waters can present higher levels of metals and other chemical compounds than normal. This is due to a bad management of industrial wastewaters and their disposal into specific receiving bodies. The main actions being developed to diminish their effects in these water bodies are the following:

- Establishment and systematic update of the National Inventory of Terrestrial Waters Main Polluting Sources[5]. Its information is used as reference for management and inspection activities, directed to both mitigate and diminish the polluting load disposal. A total of 2,227 main polluting sources has been identified, 744 of them are of domestic origin, 608 from industries, 644 from agriculture and cattle rising, and 231 municipal ones (public services).
- Wastewater disposal is characterized by national and territorial institutions, which evaluate the polluting load in receiving bodies, as well as actions for its mitigation and decrease, by means of its adequate reuse, treatment and final disposal. These actions are included in the annual investment plan of the involved institutions, and depend on the financial resources available.

- Operation, maintenance and construction of treatment and reuse systems for wastewater generated in industrial processes and social development.
- Cleaner Production practices are gradually introduced in industrial activities, with the purpose of reducing water volumes used in industrial processes as well as recycling it.
- Inspection Units from different state institutions establish their control plans (Environmental Authority, National Institute of Hydraulic Resources, Public Health, and other). Systematic inspections to polluting sources are carried out, with view to evaluate and report on the effect of wastewater disposal into the environment.
- Increase in capacity building for professionals, technicians and qualified workers that are involved in the operation of wastewater treatment systems, as well as decision-makers related to terrestrial water quality protection.
- Systematic monitoring of surface and ground waters, according to their uses, and depending on the impact caused by wastewater disposal.

All these actions are focused not only on assessing wastewater environmental impact in receiving bodies, but also on establishing measures for its mitigation or ultimate solution, by means of good practices for operation and maintenance, and determination of the required investment.

7. Water in Urban Areas

Cuban population structure is essentially urban: 76% resides in settlements comprised in this sector that includes 157 important administrative centers, 46 of them under the category of city. Many years of technologic setback, along centuries, accumulated an infrastructure that needs to be renewed in a great proportion, to reach service levels that can satisfy the needs, taking into account that potable water supply service is a basic indicator related to both human survival and hygienic conditions and well-being. Cuba has incorporated these primary rights into its social programs. For this reason, since the 1960's, a program addressed to extend these services to all the population was established for the whole country. Working in this direction, Goal 10 of the "Millennium Development Goals" (Reduce by half the proportion of persons lacking sustainable access to potable water for 2015) was already reached in Cuba since 1995, which constitutes an achievement. At present, 94.5% of the population has sustainable access to potable water, with a reduction close to 3/4 parts of the population without this service, with respect to 1990.

It was necessary to devote substantial material and financial resources, to reach this goal, since the situation of potable water service at the beginning of the 1960's was precarious: of the 300 urban core existing at that time, only 114 had aqueduct service systems that provided access through pipelines to 3.3 million inhabitants (6.5 million inhabitants, approximately, existing at this time in all country). Water supplied through aqueducts was estimated to be 200 million cubic meters per year, and approximately 50% received purification treatment, through 16 chlorination facilities and 4 purification plants. Nowadays (2008), 96.9% of the population in urban areas has access to potable water service, that is to say, 8,208,271 inhabitants; 86.9% of them are connected to the aqueduct network, 3.4% receive the service through tank trucks, and 6.6% have access facilities. Only 3.1% remains awaiting for solution, an almost insignificant figure.

Among the main problems existing in water supply services, there is the loss of large water volumes during conduction and distribution, superseded systems in bad technical state, and the need for system rehabilitation from the sources up to the purification plants. As regards significant achievements in water supply for urban areas, the following stand out:

- Increase in the number of aqueducts with treatment: 2,253 places with aqueducts that supply a population of 8,014.4 thousand inhabitants.
- Movement of EFFICIENT facilities: the objective is to achieve that they work appropriately, so that they fulfill the requirements established in the potable water and quality standards; as well as personnel training, care and maintenance of equipment and means. Of 2,538 water supply pumping stations and 64 purification plants, 2,492 and 50 attained the category of efficient, respectively.
- Stability in the supply of chemical products (chlorine gas and sodium/calcium hypochlorite): In 2008, there were 2,038 water disinfection facilities (165 using chlorine gases, and 1,873 by using sodium hypochlorite).
- Reach 100% continuity of chlorine application: At the moment, it is reported 98.4% in the fulfillment of this indicator.
- Stability in the monitoring of distribution networks (achieve higher values: residual chlorine, 109%, bacteriology, 117%).
- Guarantee the potability of water supplied by tank trucks, in places where other supply alternatives are not possible.
- Rehabilitation of purification plants as required.
- Increase in the mean service time: it reaches 10.9 hours/day.

The increase of Bacteriological Potability Index in networks, a way to certify the quality of water supplied by aqueducts, reached 94.9% at the end of 2008. The supplied water volume (FIG. 6) was 1,744.2 hm^3, which represents 98% of the foreseen plan to be delivered. Total volume which was not supplied was 98 hm^3. The main causes were: breaking of pumping equipments, electrical disruptions and pipeline break, among others. To exercise a more strict control of water conduction losses, new technologies and materials have been introduced in the operation of distribution systems

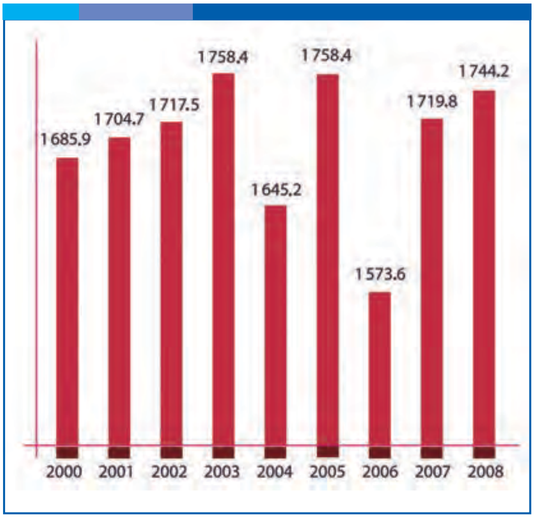


FIG. 6 Supplied Waters (hm^3), 2000-2008

(detectors, monitors, controllers, network rehabilitation, new pipelines); in water treatment (desalinization plants, purification plants, products), and in the commercial area (automated systems for invoicing and accountability). Input and output measuring equipment in treatment plants are inspected; networks are supplied with pressure gauges to control any variation, more or less important, in the system; permanent attention is given to leakage detection and locating in pipelines of the water distribution network, as well as to their timely repair; improper water uses are controlled by users, on the basis of the Program for Water Saving and Rational Use (PAURA, in Spanish).

A good example of this is found in Aguas Varadero Company, with a semi-automated operation system and reduction in loss levels, the best in the country. This system guarantees the continuous service of potable water supply, with an appropriate pressure, and has increased the treatment of served water up to 100%. It also reuses the treated sewage waters in irrigation (for gardening). This system constitutes a reference for other water supply enterprises in the country. For this reason, in Cuba, financial support to hydraulic infrastructure has been gradually transferred from a practically exclusive state budget support toward a revenue system, based on the application of rates that have a differentiated structure: domestic users are partially subsidized by industrial and commercial clients, in such way that positive commercial balances can be obtained. Additionally, in the country there is the current peculiarity of a double rate system: one in domestic currency and the other one, in convertible foreign currency. Revenues in convertible foreign currency allow financing the import expenses and some specialized services. All the above mentioned shows the magnitude of the effort and resources that are devoted to the important objective of increasing the quality of water supply services to population and economy, besides their significant impact on water and energy saving, with a higher efficiency.

With this purposes, in spite of existing financial and material limitations, the country is working on various objectives, such as:

- Network rehabilitation, in capital cities of provinces. The program began with Havana City and was extended to the rest of country, prioritizing four provinces located in western part of country. Three pipeline factories were installed and are currently in production, specialized equipment were acquired, as well as connection pieces, etc., and working teams (brigades) were created with qualified personnel.
- Rehabilitation of pumping stations and increase in energy efficiency. The Program includes the installation of 2,629 efficient pumping equipment that substitute the old, highly energy-consuming equipment; those that present breaks without solution, and also, will complete the reserves of the main water supply sources. With this program, the country will save more than 134,000 Mw-h /year, equivalent to more than 15 million CUC (Cuban convertible pesos).
- Other actions: Construction and rehabilitation of purification plants; infrastructure modernization, introduction

of new technologies, and construction of new aqueducts.

8. Water and Sanitation. Wastewater Sanitation

In 1959 at national level, 12 partial sewage systems existed, and only one wastewater purifying plant in one province; which means that at the triumph of the Revolution, the situation of sewage systems in the country was appalling. Sanitation sector, highly disregarded in precedent years, began to experience a sustained development in increase the environmental sanitation coverage. This still on-going development has reached even the most remote towns and rural communities, as an expression of the deeply rooted equality and social justice that characterize Cuban socioeconomic model.

Since then (1959), sanitation is guaranteed by means of the public sewage system (more than 4.03 million inhabitants are presently connected), and domestic evacuation through septic tanks and latrines (the latter are used by more than 6.7 million inhabitants), which allows to gradually incorporate septic tank effluents from cities and important population settlements to the existing sewage system, or to those that will be constructed. The current system benefits more than 10.7 million inhabitants. It covers 95.8% of the total population (FIG. 7), for an increment in 356,994 thousand inhabitants with respect to 2000. Sanitation cover by sectors (urban, rural) in 2008 is shown in FIG. 8. This increase in sanitation cover is supported by the infrastructure created in all these years. More than 33.9% of the evacuated sewage is treated.

Up to end of 2008, INRH had achieved a growth of its infrastructure in sanitation activities: 478 places with sewage system, for 4,965.7 Km of network length; 132 sewage pumping stations, 8 wastewater treatment plants, and 304 pond systems. As regards the 8 wastewater treatment plants, 4 of them recycle domestic wastewater for irrigation of green areas; they provide this service to

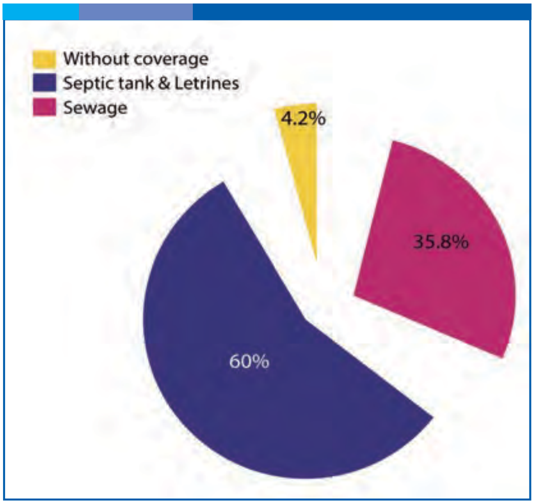


FIG. 7 Sanitation Coverage 2008 (95.8%).

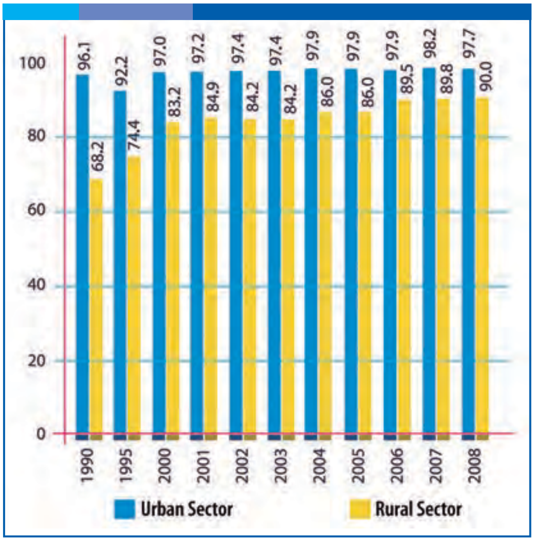


FIG. 8 Sanitation Coverage, by sectors 2008 (urban and rural).

important tourist areas, thus saving potable water that can be used for other objectives. Concerning rural population, 4.28 % is connected to sewage systems and 85.76% has septic tanks and latrines, benefiting a total of 90% of the population. There has been an increment in this indicator with respect to 2000, due to the application of simple project solutions, which allow reaching sustainability by using more economical materials and reaching wide community participation from the beginning of the program, in its design, construction, repair and operation; and by means of the participation and collaboration between the different government instances and NGOs.

The strategy of basing this program on the employment of alternative technologies and materials, as opposed to conventional technologies, has demonstrated its effectiveness. Among them, Low Cost Sewage Systems (LCSS) have been used in sanitation to increase service cover. Consequently, morbidity rates by illnesses of water origin have decreased, besides improving environmental conditions in the area, which means an increment in the population's standards of living and quality of life. The LCSS are developed with a great community acceptance, precisely as an effective alternative that reduces expenses originated by the excavation of deep trenches, construction of big inspection holes, use of a great number of large-diameter pipelines, need for mechanical equipment (with the consequent increase in fuel consumption) and other supplies, as well as the effort of qualified personnel, affectations to road network during construction, among other.

Other new alternatives are:

- Simplified Sewage System Networks: operate as the conventional ones, but with modifications in the design criteria, and simplification and minimization in the use of materials.
- Simplified Sewage System in Condominium Regime: This variant is a system of connections in horizontal property regime within a block (road segment of about 50m, approximately). They are designed so as to adapt to the backyards and common areas, in order to reduce network length inside and out of the houses.
- Decanted Sewage System Networks: Their distinctive characteristic consists of a solid interceptor tank, located between the house and the sewage system network. It is usually a septic tank that can receive wastewater input from one or more housings.

Wastewaters

The prevailing wastewater treatment systems, and those that are being gradually introduced for terrestrial water protection and management activities, are the following:

- Treatment plants for domestic and mixed wastes, built in the main urban-industrial nuclei. These plants are composed of a group of unitary processes devoted to the preliminary, secondary, and tertiary treatment (final sedimentation, chlorination).
- Compact treatment plants for domestic wastes, designed and built both in Cuba and abroad.
- Treatment plants for wastes from the

metal processing industry.

- Stabilization ponds (facultative, anaerobic and aerobic), built in series or isolated, for the treatment of domestic wastes from small population settlements or the agricultural sector. For instance, for small communities, as a secondary final treatment of previously treated pig wastes, and other similar ones. INRH system methodically controls and evaluates the total of ponds.
- Constructed Wetlands, recently introduced for domestic waste treatment in small population nuclei.

9. Water and Human Health

Waters used for human consumption, those for recreational purposes, and wastewaters used in agriculture or aquaculture should receive adequate treatment. They require constant surveillance, in accordance with the national standards established in each country. However, developing countries tend to adopt water quality guidelines and standards formulated by developed countries; although the risks, habits of the population and climate conditions are different. Measures to guarantee the covering of potable water and basic sanitation are continually increased at national level. Nevertheless, there are situations that can affect water quality, mainly if the basic requirements are not fulfilled, such as accessibility, availability, quality, quantity and continuity of service for the population.

In Cuba, morbidity by gastrointestinal infectious diseases still occupies the second cause in the demand of medical care. According to official information[6], in 2007 morbidity rate per a thousand inhabitants reported for medical care was 61.6, caused by acute diarrheal diseases, with higher incidence rate in children under five years of age (1,062), which indicates that these illnesses still affect the population and could be associated to water quality, hygiene and basic sanitation.

During 1996 and 1997, a study was carried out in 31 Cuban cities with more than 35,000 inhabitants[7], with the objective of establishing the epidemiological relationship between water quality and acute diarrhea diseases. The proposed indicators were indexes for drinking water disinfection and potability, and the medical care for acute diarrheal diseases. In 1996, disinfection index at national level reached 72.4%, and in 1997 it was 74.8%; while the potability index was 87.0% and 76.5%, respectively. An inversely proportional behavior was found in the epidemiological relationship among these two indexes and the medical care for acute diarrhea diseases. Knowing the quality of potable water in the main cities of the country, this study allowed stratifying the risks of non safe water in three risk groups: high, moderate and low. Stratification facilitated the preparation of specific measure plans, and the establishment of priorities that there were jointly analyzed with local authorities.

More recently, in a transversal analytic study developed in May and November, 2005[8], in three sentinel sites in the country (municipalities of Santiago de Cuba, Cienfuegos and Havana), diarrheas prevailed in 10.8%, being significantly higher in summer than in winter. Of them, 33.5% was associated to food consumption and

28.7% to water. In addition, 27 risk factors were studied in relation to occupation, water, food, possession of animals, trips and housing conditions. Statistical association was obtained in six factors related to food (acquisition of products in agricultural markets, not washing fruits before ingestion, not using differentiated surfaces, and not washing these surfaces before used, in places where raw meats and vegetables are cut; buying eggs more than seven days prior to their consumption and maintaining them at environment temperature at home). Three were related to water (consumption of water that does not come from aqueducts with treatment, water delivery cycle every two or three days, and direct consumption of water from the distribution system), one was linked to trips (travel to other municipalities inside the province), three to possession of animals (possession of pets and other animals), and other five associated to housing conditions.

10. Water and Economy

Between 1990 and 1994, Cuban economy experienced a strong fall of 33% of its GDP. Since 1994, it began a gradual and slow recovery that continues at present. While the GDP grew in almost 34% from 2004 to 2007 in the country, expenses in INRH systems increased in 82%. Investments were more than doubled in that period. This fact demonstrates the priority granted to this sector within the economic policy of the country. Self-financing of the hydraulic sector, through its enterprise system, assures operation expenses and maintenance of the Enterprise Groups that are in charge of aqueduct and sewage system activities (water and sanitation), use of hydraulic resources (dam operations), engineering and logistics, and hydraulic work projects. Investments in hydraulic infrastructure are financed through the State central budget. Revenues from fees and other benefits, from the population as well as the company sector, have been growing in proportion to service increments. In 2007, they reached about 600 million pesos; part of them in convertible foreign currencies, in accordance with the dual monetary system (Cuban Peso, CUP; and Cuban Convertible Peso, CUC) existing in the country. This mechanism facilitates to cover operational and maintenance expenses in convertible currency incurred by the different companies belonging to INRH.

"There is scarce evidence that governments in developing countries are reinforcing their budgets related to the water sector"[9]. Just all the opposite has been occurring in Cuba, as it can be perceived from the previous information. Bases are being created to guarantee higher development levels in this sector for the next years. For that purpose:

- Three factories of high-density polyethylene (HDP) pipelines have been installed, with an investment cost higher than 19 million pesos (90% corresponds to convertible foreign currencies). These are high-technology factories, with a processing capacity of more than 25,000 tons of resins per year, and they will cover 100% of the current needs in the country. To complete these investments, injection and thermo-fusion machinery have been contracted to produce parts and accessories, for more than 7 million USD. For the coming years, HDP resin production is foreseen as part of the development of the national petrochemical industry. It will cover national needs for pipeline and parts productions.

- Purchase of construction and transportation equipment to reinforce the constructive capacity of INRH enterprises.
- Acquisition of 700 power generators, with capacity of approximately 125 MW. These generators are able to protect 648 important objectives belonging to the water distribution system, in case any failure occurs in the national electro-energetic system. The installation of these generators is 90% fulfilled in the whole country, and their acquisition cost was about 48 million USD.
- As part of the National Energy Saving Program, 2,672 water pumping equipment of high energetic efficiency have been purchased in the hydraulic sector. They are in the final installation phase, and will substitute a similar number of inefficient equipment, in different aqueducts of the country. Their cost has been close to 45 million USD, but they will save 15 million USD / year (in terms of energy saving). Moreover, they will benefit water supply service in quality and quantity.
- Acquisition of about 270,000 water pumping equipment of low energy consumption to be installed in housings with more than one floor. They are in the final installation phase and will substitute inefficient equipment, with the subsequent increment in energy saving, while improving water supply service to the population.

Drought Effect Mitigation Program. This Program has been executed for some years. It consists of water transfer construction (among basins and provinces); rehabilitation of hydraulic networks and pipelines; construction of new aqueducts and treatment systems, among other.

11. Water for Energy and Impact of Dams

The use of water energy in Cuba, as a source for electricity generation, dates back to the beginning of last century, when small hydroelectric plants were put in exploitation. Their ruins still remain as samples of the traces of hydraulic energy use for different purposes, especially, in coffee plantations and to operate grain mills. The 1980's marked the real beginning of the studies, construction and development of the hydro-energetic activity in the country, due to fuel shortage and increase in its prices in the international market. The need to take electricity to small communities in remote mountainous areas found in this source a viable way, whose use was considerably intensified with a wide program directed to its development and maintenance, with the purpose of elevating the standards of living of these residents and substituting diesel plants.

Hydroenergy.

Current Situation (2008). Classification by power ranges (according to the Latin American Energy Organization). Cuba has 137 micro-hydroelectric plants, 35 mini-hydroelectric plants, 7 Small Hydroelectric Power Stations, and one Big Hydroelectric Power Station, for a total of 180 facilities (including 31 stations that contribute energy to the National Electro-Energetic System). The installed power is 62.2 MW, distributed in 9 provinces and 38 municipalities of the country. The benefited inhabitants, residents in intricate mountainous and rural zones of difficult access, reach up to 34,990 (including the electrification of 78 medical clinics, 138 schools and other 188 economic and social objectives in these intricate zones).

12. Flood and Drought. Intensity, Impacts on Human Health and Economy

Floods are the most common type of disaster in the entire world, being estimated that they constitute 40%. In the last 25 years, and according to data published by Stop Disasters magazine, deceased by floods represent 8.6% of the total of deaths, and 80% of the wounded by all the natural disasters.

The frequent presence of tropical storms of remarkable precipitation capacity in the Caribbean area, in months between May and November, exercise a notable influence on the country's hydrological regime, where the superficial flow regime behaves in accordance with rain distribution: major flows take place in the rainy period, almost always related to tropical storms. Floods in Cuba are also associated to the ground modifications, produced by inadequate agricultural practices, pruning of trees, fires, urbanization, bad constructive practices, and other interventions inappropriate for the environment, or the combinations of these.

In Cuba, damages produced by these phenomena are also considerable: the sea penetration that affected Santa Cruz city, in the south of Camagüey province, in 1932 caused more than 3,000 dead and missing; floods associated to Hurricane "Flora", in 1963, in the eastern part of the country, caused more than 1,000 casualties. Fortunately, and as a response to the impact of this hurricane, it began the development of an efficient Civil Defense System that preserves human lives from these natural disasters. It is internationally recognized that in Cuba deaths are minimum in these circumstances, almost always due to the victims' irresponsible acts. Taking into account the high vulnerability to extreme climatic events, intense precipitations and floods, special attention is granted and major efforts are devoted to hydrological prevention in Cuba. In this sense, INRH is taking the first steps in the automation of the Hydrological Prevention and Early Warning Systems, in basins that are highly vulnerable to the effects of extreme events, and with conditions of high flood potentiality, where the population and important material resources are jeopardized. As it is foreseen, these systems will include the automation of the measurement of hydrological cycle variables (a monitoring network has been designed, in correspondence with key needs for protecting and managing hydraulic resources in these basins); real-time data transmission; data processing; hydrological and hydraulic modeling; operation of hydro-mechanisms. All these actions are address to offer support to decision-making.

Drought has also been exercising a decisive role in the hydrological cycle, particularly on superficial and underground hydraulic resources, their availability and characteristics of their management and exploitation. It has driven to alternative solutions in affected areas, regarding water supply, irrigation and energy generation. These events have caused considerable direct and indirect impacts on economy and society. The last of them, the drought from 2003 to 2005, caused that of the 239 reservoirs in exploitation, 114 did not reach 25% of its use and 41 of them were below "dead volume" at the end of January 2005. At given times, it was necessary to supply water to more than two million people simultaneously, using different means of transportation, such as boats and railroads.

Direct losses were more than 1,000 million USD. In response to these noxious events, advanced Surveillance, Diagnosis and Early Warning Systems, are continually being developed in Cuba for Meteorological, Agricultural and Hydrological Drought, supported by the scientific research that deepens in the knowledge of causes of these phenomena. These systems allow advancing in the forecasting of these events, as well as in determining the danger they represent for different localities in the country. They are part of the studies on danger, vulnerability and risks due to climatic events that are being developed for the whole country at present, in order to reduce their impacts.

13. Legislation

At the end of XIX century, the existing legal base in Cuba related to terrestrial waters was countersigned by the Spanish Law on Waters of 1879, published in the Gazette of Havana (February 26, 1891). It was extended to the Island of Cuba on January 9th, 1891, by Royal Decree dated that same year. Its Regulation (January 13th, 1891) constituted the first ordinance of the highest juridical rank that specifically regulated aspects related to water in Cuba. These legal instruments were in force up to July 1st, 1993, when Decree Law No. 138 "Of the terrestrial waters" became effective.

Outstanding Milestone in Cuban Legislation as regards terrestrial waters (February 24th, 1976): the first Constitution of Cuban Republic was promulgated, with a socialist system. It establishes new legal bases with respect to terrestrial waters, and includes in its Article No. 27 that: "to guarantee the well-being of the citizens, the State and society protect nature. It concerns the competent government bodies, and also each citizen, to ensure that waters and atmosphere are maintained clean, and the soil and fauna are protected". (Constitution of Cuban Republic, Consulted legislation).

With the amendment carried out to this constitutional text in July 1992, the National Assembly of the People's Power (Cuban Parliament), prior consultation to the whole population, modified the mentioned article to adjust it to the principle that propitiates the rational and sustainable use of natural resources. It was finally written as follows:

"The State protects the environment and natural resources of the country. It recognizes their close linkage to sustainable socio-economic development, to make human life more rational and guarantee the survival, well-being and security of current and future generations. It corresponds to the competent government bodies to apply this policy. It is the citizens' duty to contribute to the protection of water and atmosphere, and the conservation of soils, flora and fauna, and the whole rich potential of nature". (Consulted Legislation). It should be highlighted that Law No. 33, "Of the Protection of Environment and Rational Use of Natural Resources" had been promulgated on January 10th, 1981, establishing the basic principles for environment conservation, protection, improvement and transformation, and the rational use of natural resources. It was pointed out that these resources comprise mainly terrestrial waters, among other.

Within legislative improvements in the country, and the need to deliver a juridical instrument to regulate the increasing activity regarding terrestrial waters, in agreement with the policy of natural resource integrality that the State promoted, Decree Law No. 138 "Of the Terrestrial Waters" was promulgated on July 1st, 1993.

This Decree, still in force, had the objective to develop the basic principles established in the Constitution of Cuban Republic and in Law No. 33, accompanied by other ordinances for its best application, among which stand out:

- Decree No. 199, of April 10th, 1995. Set in force the Contraventions of Regulations for the Protection and Rational Use of Hydraulic Resources.
- Decree No. 211 of August 9th, 1996. Of the Contraventions of Regulations on aqueduct and sewage services.
- Resolution No. 25 (Ministerial), of October 27th, 1993. Set in force the Rules for State Inspection in hydraulic resource issues.
- Resolution No. 67 (Ministerial), of May 15th, 1990. Defines the necessary measures to protect "Vento" Basin (source of water supply to the Havana's population).
- Resolution No. 24 (Ministerial), of May 8th, 1999. Approves and sets in force the sanitary or ecological spending of natural water courses interrupted by constructed reservoirs.

The promulgation of Law No. 81 "Of the Environment", dated on July 11th, 1997[10] that derogates the previous text in environmental issues, determined the need to begin a review of the Decree Law in force in relation to waters, in order to adequate it to the juridical system. This work has not concluded yet; however, it has been decided the promulgation of complementary ordinances that allow its best application. An outstanding juridical instrument, due to its significance to manage and protect hydraulic resources in Cuba, has been the creation of the National Council of Hydrographic Basins (April 1997), supported by Agreement No.3139 of the Executive Committee of Cuban Council of Ministers. This Council is the maximum coordinating government body, in aspects related to planning and management of hydrographic basins in the national territory[11]. The results of its performance have allowed enriching the concepts related to the integrated management of basins, as nucleus of the National Project on Integrated Management of Hydrographic Basins, began in 2008. Recently, the Council of Ministers approved the Decree No. 280/2007, March, 2007, that in its chapter III institutionalizes the National Council of Hydrographic Basins.

As complementary instruments, there are legal ordinances addressed to the predominance of rationality in water use, among which stand out those related to the approval and set in force of water consumption indexes for non-agricultural economy sector (1991); to establish the requirement of approval by INRH to extract water totally or partially from reservoirs, during the catch of species or for other ends (1994); approval of methodology to elaborate the Water Balance, and its assigned plan (1998); approval and set in force of total net standards and the efficiency coefficient to determine the gross standards of the main agricultural cultivations (1999).

14. Water Conflicts

Its insular conditions exclude Cuba from 90% of world population that lives in 145 countries with shared hydrographic basins[12], where water management, according to its scarcity or abundance, would constitute a potential focus of conflicts. However, the physical geographical characteristics of the archipelago, its geographic location that determines a high vulnerability to extreme hydro-meteorological events, the elongated and narrow shape of its mainly island, the space-time distribution of its water resources, together with the ambitious socioeconomic development program stated by the revolutionary government since January 1959, have paved the way for a water management strategy. This strategy has been supported by the creation of a wide hydraulic infrastructure, to give response to society, economy and environment in a sustainable fashion.

The country is in favorable conditions to solve any possible conflicts among water users, given the legal base available (see section 13. Legislation), together with the institutional basis, supported by INRH – as State entity in charge of administration, planning, control and protection of freshwater supply and sanitation. Different water uses do not compete among themselves, and priorities are defined according to their importance. Water for population is the first one.

The main instrument for water management is constituted by the Annual Balance of Water Uses. This is a process based on resource availability at the end of the rainy period, and the demands from different users.

The Annual Balance of Water Uses is discussed and approved by the local government, in connection with INRH structures at this level, and finally, it is set in force by means of a Resolution signed by INRH President, passed in January each year. INRH President has legal faculty to modify it, if necessary. INRH, through its State Inspection entity, controls the fulfillment of this legal instrument, and applies measures for contraventions to juridical as well as natural persons, trough regulations in force.

INRH has the faculty to stop illegal activity, if necessary. Nevertheless, the dynamics of socioeconomic development, or the hydrologic cycle behavior, can lead to extreme situations that cause the adoption of restrictive measures, of extreme control, national or multi-sectoral strategies, and the elaboration of legal documents, such as joint legal resolutions among different economic sectors. Some examples of possible "conflicts" are specified below, and the mechanisms to solve them are mentioned in parenthesis:

1. Aquaculture and Water Supply to Population. Intensive fish culture in reservoirs which are used for water supply to population is forbidden, and established in Decree Law 138.

2. Aquaculture and Agriculture. The water mirror to guarantee both uses is established in the Annual Balance of Water Uses.

3. Hydroelectric Power Generation. It is subordinated to agriculture and water supply uses.

4. Environment and Reservoirs. Maintenance of ecologic equilibrium –ecologic discharge– in the regulated flow is planned within the Annual Balance of Water Uses (by Resolution of INRH President). The different drought episodes experienced Cuba, and limited water availability that these imply, have conducted to certain level of "conflicts" among users in some occasions. In these cases, a national strategy has been harmonized and implemented, with the participation of the State Central Administration Organizations involved in the problem. Actions are identified for both the rational water use and its management, and the establishment of technologic or organizational measures in a short, medium and long term; together with strategic projects to increase water availability for different uses. Water transfer among regions (provinces) is one of the strategic projects with a greater scope that has been developing in the country (FIG. 9) to solve potential conflicts that, above all, do not contribute to the population's socioeconomic stability and quality of life. In objective terms, an alternative to solve conflicts is to increase the application of efficient and sustainable technologies for water uses, achieve water management with a multi-dimensional approach, and foster the participation of all the social stakeholders involved (population, users, technicians, and decision-makers).

15. Water Governability

As a concept, and, in accordance with UNESCO[13], "water governability is defined by the political, social, economic and administrative systems that are in operation and affect, directly or indirectly, the use,

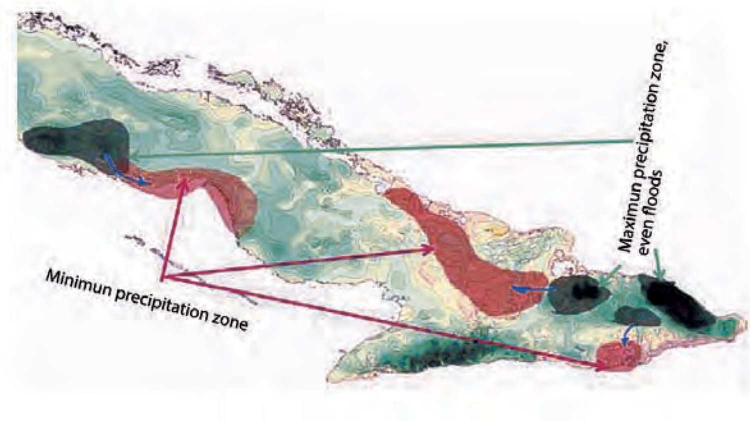


FIG. 9 Water Transfer Among Region. Strategy Project

development and management of water resources, as well as the distribution of water supply services at different levels of society".

Water Governability: Conditions in Cuba

The Constitution of Cuban Republic, in its Article 11, establishes the legal foundation as regards water: "The State exercises its sovereignty over the whole national territory, integrated by the Island of Cuba, the Isle of Youth, the other adjacent islands and keys, inner waters and territorial sea, in the extension fixed by law, and the air space that extends above all these". Article 27 of this Constitution (mentioned in section 13 of this Chapter) recognizes the close link between water and sustainable socioeconomic development, as well as the citizens' duty to contribute to its protection. Other legal instruments complement and broaden the effective legal base with respect to waters, such as Law No. 81 "Of the Environment", and especially Decree Law No. 138 "Of the Terrestrial Waters", among other.

Administrative Organization (Institutional)

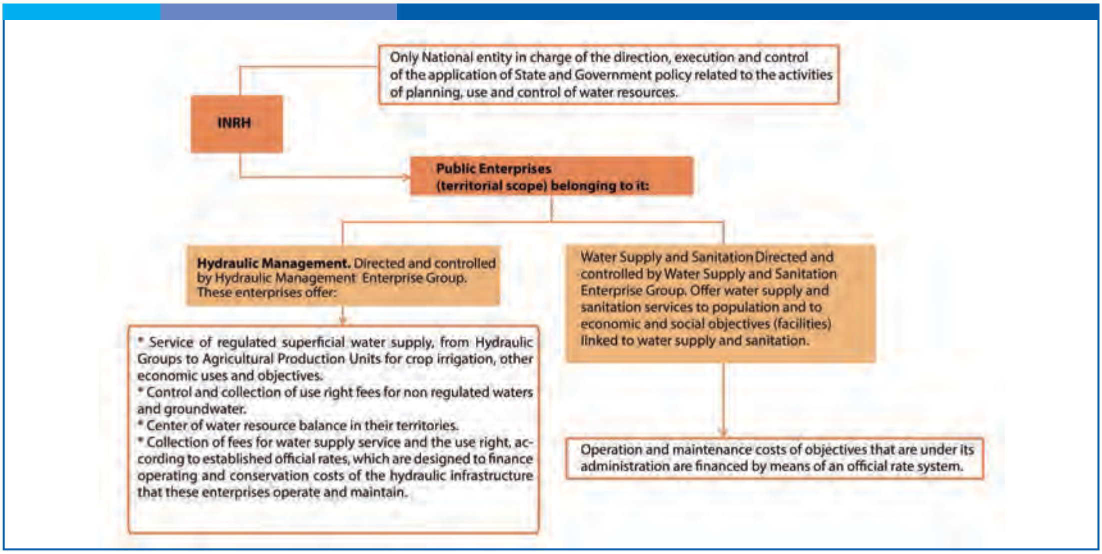
The existing institutional structure to implement water governability mechanisms in Cuba, is as follow (Box 1).

Observation networks of hidrologycal cycle variables and water quality are operated by INRH system, entity that manages degenerated data bases. This data bases constitute source of official information for the whole nation.

Investments in infrastructure are financed by the State budget. Consequently, the whole hydraulic and hydro-sanitary infrastructure in the country is State property.

Water Governability Mechanisms

Planning. In Cuban conditions, the Annual Water Balance constitutes the cornerstone in water management. It has a national scope and a territorial significance: 1) it expresses assigned water volumes for different economic and social activities; 2) it takes into account the actual availabilities foreseen for one year



Box 1. Administrative Organization

in water supply sources, and the measures addressed to the protection of water and aquatic systems, Table 5.

Execution

It corresponds to Hydraulic Management Enterprises the execution of the Annual Water Use Plan, through the operation of the hydraulic infrastructure in their charge. Besides the responsibilities described in previous diagram, these entities execute the following activities, among other, in their performance area:

- Measurement of water delivered to users. By means of the development and constant improvement of the exploitation hydrometry.
- Collection of fees applied to users. For regulated water supply service, and use right of non regulated waters and groundwater.
- Eventual proposals to modify the Water Use Plan. Under unforeseen conditions of hydrological cycle variables behavior, or because of production and services needs.
- Hydrological Prevention. In extreme events, Hydraulic Management Enterprises play an important role before, during and after the occurrence, in relation to the protection of infrastructure that they operate, and in the adaptation of their operation to the existing conditions. In these circumstances, their performance is fundamental, together with the Civil Defense plans and actions in the territory of their intervention.

Integrated Water Resources Management (IWRM)

Even though some IWRM elements have been present in water planning and control systems in Cuba for many years, to which the institutional and socio-political stability of Cuban model have contributed, national authorities of the hydraulic sector have closely pursued the conceptual development on water management that has taken place in the international scale, which have derived to an IWRM approach. Therefore, within the existing institutional and legal framework, important steps have been taken in the last years that have enriched the environmental, social, political and economic dimensions of water management, toward an IWRM approach[14]. These elements are focused in the issues briefly summarized below:

Implementation of current approaches for IWRM in Cuba

- Creation of the National Council of Hydrographic Basins. Fifteen Territorial Councils of Hydrographic Basins, and six Specific Advisers; they constitute an

Table 5. Annual Water Balance

Elaboration of Annual Water Balance	Every year, users must present justified water demands, in accordance with the foreseen activity level in their production or service plans, their established consumption and efficiency standards. It is referred to each supply source, user and specific water use, in each quarter of the year that is planned. It constitutes the ruling document for sources operation and delivery controls. The prescriptions that it contains are mandatory for all the water user entities.
Approval of Annual Water Balance	**INRH** is the national legal authority to approve it. Once approved, it constitutes the **Water Use Plan** for the corresponding year, and it is an integral part of the **National Economy Plan.**

important framework for a better approach to integrated water management in its relation to the other environmental and socioeconomic components.

- Definition of nine basins of national interest. They include six shared basins and 53 high-priority basins of provincial interest for the Council at this level. Elaboration and control of the Water Use Plan for these basins.
- Beginning the constitution of Water Users Communities. These communities propitiate and avoid possible conflicts of interest among users and their greater participation in decision-making. They provide support to Water Management Enterprises during their effort to increase efficiency in the water use.

In Cuba, the funding policies based on water supply service rate for domestic, commercial, industrial or agricultural uses are governed by the principle of costs recovery.

Within this context, rate design has the objective of achieving efficient water uses, with a price scale that stimulates lowest consumptions and penalizes consumption excess.

Economic Dimension of Water Management. Efficient Use

Full development of these policies implies the measurements of water deliveries. In the Cuban case, it is in the residential sector where water delivery measurement is poorly developed (only 4% of coverage).

At present there is an ongoing investments process that should increase this coverage to more than 20% in the next years. The rest of the sectors have acceptable water delivery measurement coverage.

An Experience

Since 1994, the International Economic Association for Aqueduct and Sewer Systems in the tourist destination of "Varadero", and the Concessionary Society for Management and Promotion of Aqueduct, Sewer, Cleaning-up and Drainage Services, S.A. (named "Aguas de La Habana" in commercial issues), are two contract modalities that are operating in Cuba with international partners. Their essential purpose is to incorporate state of the art technologies in aqueduct and sewage management. "Aguas de La Habana" is commercially in charge of these services at eight municipalities of Havana City. Both contracts were signed by "Aguas Barcelona" Group, from Spain, and INRH. Economic and important social benefits are being obtained.

16. Global Change Scenarios

One of the evidences of global changes in the Caribbean region is the increase in hurricane frequency in the last years: Michelle (2001), Lily, Isidora (2002), Claudette (2003), Charley, Iván (2004), Dennis, Rita, Vilma, Katrina (2005). Prevision and mitigation/adaptation strategies that allow facing the consequences of the evident global changes, and their impacts on economy and survival of insular states, and particularly as regards Cuba, it is reason of concern for the government and the institutions involved in the actions that are being undertaken at present. Scientific sector and Civil Defense integrate pertinent studies. The government endows key institutions with material and financial resources, and necessary support, to elaborate recommendations and measures that Cuban society has to take, with a view to its readiness to cope with global change effects. All sectors of economy, including water resources, participate in this strategy, which include adaptation measures and vulnerability decreasing, by mean a Hydraulic Resources Program identified.

17. Water, Culture and Religion

Culture has been defined by UNESCO's Universal Declaration on Cultural Diversity as "the set of distinctive spiritual, material, intellectual and affective features that characterizes a society or a social group, and includes, in addition to arts and literature, the ways of life, ways of living together, value systems, traditions and beliefs."[15] This international organization has recognized the role of water in culture, in its linkage to the development of mankind. Its Web site, in its section "Water and culture", includes research contributions of countries on this subject, with manifestations that date back to remote times, to the beginnings of ancient civilizations. In that context, it is indicated:

"In Greek mythology, Okeanos (Ocean) was the titan and primogenitor god of the great river, Okeanos, which surrounded the world, original source of all freshwater in the planet that included rivers, wells, springs and clouds".[16] Associated to the development of Cuban nationality, and as part of the "distinctive spiritual, material, intellectual and affective features that characterize (Cuban) society", water has been and is still integrated to "its ways of life, value systems, traditions and beliefs". Spanish immigration in Cuba until the XVIII century was mainly Andalusian. Houses that were built in the period that Professor Pradt denominates as "Cuban Pre-Baroque" show a great influence from this southern area of Spain, enriched by Arab culture. That influence is manifest in paneled ceilings, roofing tiles, pottery, and in the "atanor", tube or pipe to carry water to the tank, well or cistern, excavated in the houses' patios to collect rainwater. In Camaguey, water was stored in typical "tinajones" (large earthen vats) that, for their utilitarian and ornamental value, became a symbol of this Cuban province.

At the time when Cuba was a Spanish colony, during the government period of Captain General Miguel Tacón, Havana city was garlanded with fountains, additional to those already existing.

The fountains "La Columna" (the Column) or "Ceres", "Los Aldeanos" (Villagers) or "Las Frutas" (Fruits), "Los Sátiros" (Satyrs) or "Las Flores" (Flowers), and "Esculapio" (Aesculapius) date back to 1830's. The fountain "Los Leones" (Lions), made by sculptor Gaggini

FIG. 10. The fountain "Los Leones" (Lions), photo by Richard Molina, Environment Agency, Cuba.

and architect Tagliafichi, was inaugurated in San Francisco Plaza in 1836; and a year later, the symbolic fountain "La India" (Indigenous girl) or "Noble Habana" (noble Havana), also by the mentioned Italian artists, was placed in front of the "Campo de Marte" (a plaza) and at one end of the "Paseo de Extramuros" (outside-wall promenade). In 1838, a fountain of Neptune, by an anonymous author, was inaugurated at the seaside in front of the former Captainship of the Port. Fountains were used not only to adorn the walks and tree-lined avenues of the villa, but also to make livelier and create a fresh atmosphere in inner patios of residential mansions.

a) Water and Poetry: On the outstanding poet Dulce María Loynaz, it has been expressed that in "Games of Water" (1947), she sings to the nature in one of their elements (water), big and simple, seawater, pond or river, free or prisoner, fugitive or static. Her beautiful poem "To the Almendares", a river in Havana province located, it is an example of the encounter of human things and nature.

b) Water and Painting: First appearance of a black man image in Cuban painting is associated to miner - medicinal waters. Nicolás de la Escalera (1734-1804) paints to him in a work where the first Count of Casa Bayona appears, together with his family and the slave that translated to him until the medicinal waters existing in his lands, where he could cure certain illness that he suffered in his skin.

c) Water and Music: The natural sounds of soft or torrential rain, and of meek or brave currents, in quite or flooding rivers, and also those of the Cuban rural zones, they have wakened up the sensibility of composers of the XX century such as Pablo Ruíz Castellano, author of the titled symphonic works "Río Cauto", "Monte Rouge" and "Escenas Campestres."

d) Water and Religion. UNESCO[15]: Water performs a fundamental function in numerous religions and beliefs around the world. As a "source of life", water represents birth and revival. It cleans the human body and, therefore, also purifies it. These two main qualities grant water a symbolic, even sacred, condition; thus becoming a key element in religious ceremonies and cults. This reality is not alien to water culture in Cuba, in relation to religions of "Yoruba", "Conga" and "Carabalí" origins (widespread and practiced in the country to a large extent at present), from times as remote as the arrival of black slaves (1511) coming from Africa[17].

The persons in Cuba that still practice Afro-Cuban religions, in ritual ceremonies that evoke the "Supreme Being" (God) or protective deities, as well as in acts of divination, begin by sprinkling the ground with fresh water contained in a specific cup (jícara), and they solemnly pronounce: "Omi-tutu: Ana-tutu, tutu-laroye, tutu-ilé" its meaning may be varied, but never changes its essence (Note from Editor).

These are words that summon to the essence, to become aware that water, faith and creative will are needed to bring about development and guarantee the future, from a religious point of view.

FIG. 11. The fountain “La India” (Indigenous girl) or “Noble Habana” (noble Havana) photo by Richard Molina, Environment Agency, Cuba.

Omi tutu:	**Fresh water (in order to achieve)**
Ana tutu:	Fresh brain
Tutu Laroye:	Fresh Elegguá (deity described as mischievous in the Yoruba pantheon. A kid owner of the road, who daily opens and closes the roads of all mortals)
Tutu Ilé:	Fresh house

Source: Leyda Oquendo B. personal communication

18. References

1. García Fernández, J. M., Cantero Corrales, Luís (2008). Indicadores globales para el uso sostenible del agua: caso cubano. Revista Voluntad Hidráulica No.100, La Habana: 12-19
2. A.K. Chapagain y A.Y. Hoeskstra (2004). UNESCO-IHE. Water footprints for nations. Vol No 1. Main Report.Research Report Series No 16. November 2004
3. Plan de Uso del Agua Año 2009. Informe Oficial del INRH, Cuba. Oficina Nacional de Estadísticas (ONE). Reporte 2010
4. Rey R. Reporte oficial, Ministerio de la Agricultura, Cuba (ONE, 2010)
5. Inventario Nacional de las principales fuentes contaminantes de las aguas terrestres, 2008. Inédito. Documento de trabajo. Archivo INRH, La Habana
6. Dirección Nacional de Registros Médicos y Estadísticas de Salud del Ministerio de Salud Pública de Cuba. 2007, Disponible en URL: http://www.dne.sld.cu/desplegables/indexcuab.htm
7. Aguiar, P., Cepero, J. A., Coutin, G. La calidad del agua de consumo y las enfermedades diarreicas en Cuba, 1996-1997. Revista Panamericana de Salud Pública, 2000, 5: 313-18.
8. Aguiar P, Castro A, Coutín G, Triana T, Fernández K, Hernández R, Navarro R. Factores de riesgo asociados a de las enfermedades diarreicas agudas en tres sitios centinelas de Cuba. En Memorias del VIII Congreso Asociación Interamericana de Ingeniería Sanitaria y Ambiental (AIDIS), Ciudad de La Habana, 22-25 mayo, 2007.
9. En: Segundo Informe de Naciones Unidas sobre el desarrollo de los recursos hidráulicos en el mundo – p. 82

10. Fernández-Rubio Legrá Ángel. Ley 81/97 Del Medio Ambiente en más de 150 preguntas y respuestas. Ministerio de Justicia, La Habana 1999.
11. Gutiérrez Díaz Joaquín. Gestión Integrada de Cuencas Hidrográficas en Cuba. Ponencia. Centro de Información, Gestión y Educación Ambiental del Ministerio de Ciencia, Tecnología y Medio Ambiente de la República de Cuba.
12. PNUD (2007), Informe de Desarrollo Humano, 2006. Más allá de la escasez: Poder, pobreza y la crisis mundial del agua.
13. Boletín Semanal Portal Agua No. 165, UNESCO. Sección ¿Sabía Ud. Qué? Hechos y cifras sobre la gobernabilidad del agua 24 de noviembre de 2006.
14. García Fernández J. M. Aplicación del enfoque ecosistémico a la Gestión Integrada de los Recursos Hídricos. Revista Voluntad Hidráulica No 99. Año 2007.
15. Sección "Agua y cultura", sitio web de la UNESCO: "El sonido de nuestra agua".
16. http://www.waterhistory.org/histories/nile/ y de la sección Okeanos del Proyecto Theoi http://www.theoi.com/Titan/TitanOkeanos.html
17. Oquendo Barrios, L (1999). Trata, esclavitud y cimarronaje en América. Cronología (1492-1890). Revista de la Asociación Cubana de las Naciones Unidas, Documentos para el análisis. No. 2, pág.9, La Habana.

Chavon River in Dominican Republic

Potable Water and Sanitation in the Dominican Republic

R. Osiris de León

Academia de Ciencias de la República Dominicana

1. Introduction

Since antiquity until our present day, human beings have settled at the main river banks since it is absolutely indispensable for life and there is no way any form of life can live without this molecule which on uniting two hydrogen atoms with one atom of oxygen also unites the individuals that share a neighboring space near a river flow.

Beginning slighly more than five thousand years ago, the Egyptian dynasties grew and flourished along the torrential River Nile, which governed a dozen pharohs which settled in their palaces, their temples, their monuments and their tombs in the vicinity of the Nile River, but sometimes it is only those who live in the desert provide a real value to water as the source of life.

During the past century world population tripled, while the consumption of water increased sixfold, it is thus estimated that for the year 2025 some 460 million people will be living in countries that have water problems because six million of the planet's inhabitants today use 54% of all available fresh water in rivers, lakes and subterranean aquifers, and although 70% of the planet is covered by water, this volume is barely made up by 3% of fresh water, with the limitation that two thirds of fresh water is frozen on the polar caps, with the only 1% of the remaining total available for consumption while the population grows and grows and water contamination increases and increases.

However, the accelerated population growth and the economic limitations of the vast majority encourages hundreds of thousands of people to live along the banks of rivers, streams and ravines, without adequate potable water service and without sanitary sewage, provoking the growing contamination of surface waters that convert rivers, streams and ravines into true urban sewers, which makes people to make use of a smaller potable water supply, implicating high treatment cost and marketing costs, which in the future will convert potable water into a commodity available only within the reach of the wealthy.

The lack of a sanitary sewage system has led cities like Santo Domingo use toilet water through draining wells that unload feces in the same subterranean waters that we collect in drill wells, while poor people that live by the river, steams and ravine banks and ravines and which generally defecate at the river banks for lack of latrines, contaminate surface water with bacteria (Vibrio cholerae, Escherichia coli, Salmonella) and in that manner transmit diseases such as Cholera, Salmonella and Amebiasis, to the extreme that today the Dominican Republic is on red alert due to the presence of Cholera in the country's main rivers.

In the same manner, the social and environmental struggle against the installation of a cement mining operation would contaminate the hydro geological region of Los Haitises, a struggle in which the people defeated the government, provides evidence that the Dominican Republic is beginning to create awareness on the need to protect water quality, but government awareness is still lacking for the adequate management of residual waters, garbage and urban growth along river, streams, ravines, lakes and lagoons, and entrepreneurial awareness to stop depredation and contamination.

2. Subterranean Waters of the Eastern Coastal Plains

Upon evaluating fresh waters we find that 68.7% are found in glaciers and polar caps and is not available, 0.26% is in lakes, 0.006 is in rivers, 0.043% is in the atmosphere and biomass, and a very important 30.10% is located in subterranean aquifers, which is to say, that of the total fresh water available, 96% is subterranean waters, which in the last decades have been over exploited and severely contaminated, creating uncertainty as to the water for the future.

It is known that a vast majority of countries depend to a great extent on the exploitation of subterranean waters, which have been over exploited by the growth in housing, agriculture, tourism and industries in general, an overexploitation which has produced an accelerated abatement in ground water levels and an extraordinary advancement of saline intrusion in the coastal zones, mainly in the tourist zones.

In the case of the Eastern Coastal Plain, the main aquifer existing in the Dominican Republic where thanks to the vertical drainage process given in the cavernous limestone reefs that make up an extensive plain which runs from Santo Domingo to Cabo Engaño there is an annual net replenishment to the order of 1,100 million cubic meters of water annually. In the zone of Boca Chica and La Caleta, the ground water levels are very near sea level, and a few times are above the height of 1 m.s.n.m., which explains the important and extensive saline intrusion wedges existing in the entire zone, where in many stretches the hydraulic gradient is inferior to 0.1%.

Within the limestone, transmissibility is very variable since in some cases they are superior to 8,000 m^2/day with storage coefficient variables between 0.002 y 0.15.

Generally the ground water abatement levels are minimal for the large volume of water extracted, which is the evidenced by the aquifer's great potential although the exploitation of this aquifer is limited by the high risk of saline intrusion previously referred to.

An hydro-geological study conducted some years ago by Geofitec, S.A. and which covers the area northwest of Boca Chica, concluded that:

1 The aquifer Brujelas–Casuí, located to the northeast of Boca Chica, is covered by a superior horizon of a clay nature which varies between 1 y 48 meter thick, with an average thickness nearing 13 meters.

2 This clayish covering hinders the direct replenishment to the aquifer which indicates that all replenishment comes from the north, northeast and northwest zone, which is to say the zone of Los Haitises.

3 The ground water level of the zone northeast of Boca Chica is approximately 24 meters deep, whereby it is currently static fluctuating between 0.5 y 1.5 meters above sea level.

4 Underneath the ground water level the stratigraphy is comprised primarily by limestone sand, calcareous clasts, sandy limestone and a much reduced proportion claylike waterproof materials noting that the sandy materials are in a greater proportion which favors the permeability and transmissibility of the aquifer.

3. Quality of the Subterranean Waters of the Coastal Plain

Saline Intrusion Due to Overexploitation of the Aquifer.

The most preoccupying concern in the Eastern Coastal Plain aquifer is the overexploitation of the subterranean costal water, primarily in Boca Chica and Bavaro, since to the northwest of Boca Chica the saline intrusion has advanced 15 kilometers inland, utilizing subterranean waters from that extensive costal fringe and in the tourist cluster of Bavaro the saline intrusion has advanced more than 3 kilometers, placing in danger the future potable water supply in this important regional tour cluster and endangering the expansion of this tourist site, because today more subterranean water is extracted than the net replenishment received by the aquifer, this being the cause of the saline intrusion, which indicates a limitation

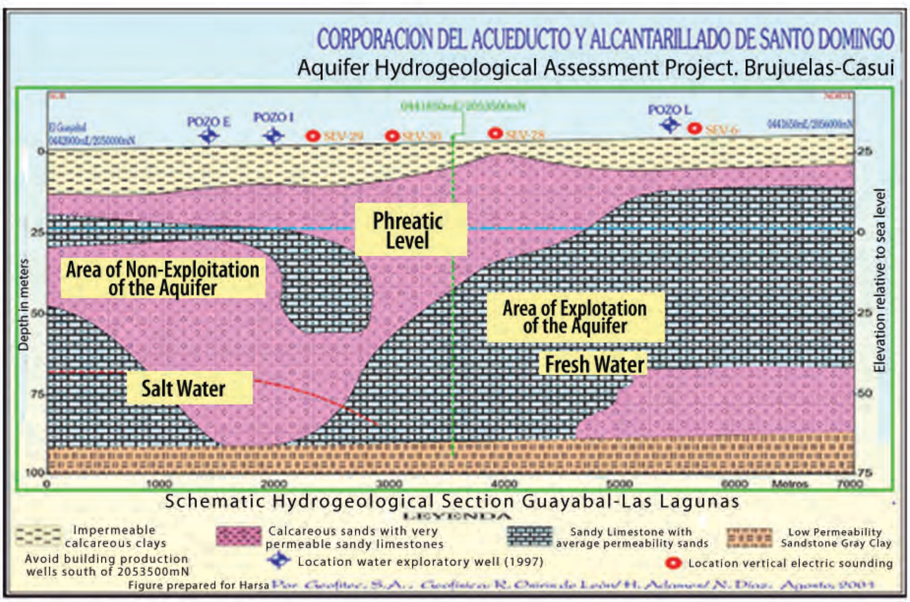


FIG.1. Hydro-geological Schematic Section C-D Guayabal-Las Lagunas. Brujuelas-Casui

for the supply of subterranean water to the zone's future tourist projects. The dotted line in the following map shows the saline intrusion zones. Table 1, shows the results of studies by us in Boca Chica.

Table 1. Studies in Boca Chica

Parameters	Sample m1	Sample m2
Alkalinity (mg/L like $CaCO_3$)	260.00	120.00
Zinc (mg/L)	0.10	0.03
Chlorides (mg/L)	210.00	205.00
Total coliforms (CFU/100 Ml)	10.00	6.00
Color (U Pt.Co)	45.00	4.00
Hexavalent Chrome (mg/L Cr^{+6})	NA	NA
BOD 5 (mg/l BOD 5)	21.00	5.00
COD (mg/L)	78.00	13.00
Total Hardness(mg/L like $CaCO_3$)	425.00	240.00
Phosphates (ppm)	0.01	NA
Iron (mg/L)	0.20	0.10
Nitrates (ppm)	0.01	0.02
Nitrites (ppm)	NA	NA
Ammonium-nitrogen (ppm)	0.02	NA
pH	8.50	8.10
Suspended solids (mg/L)	825.00	334.00
Sulfates (mg/L)	0.03	0.02
Total Dissolved Solids (mg/L)	402.50	390.50

Note: NA Not Available

The waters sampled in the survey indicated that the chloride levels were below international standards, that is to say, below 250 ppm, which clearly indicates that there hasn't been any saline intrusion in this area that characterizes the northeastern zone of Boca Chica where there are exaggerated levels of chlorides registered at a depth around 65 and 70 meters in the wells where the values reached 8,000 and 9,500 ppm of total chlorides.

The potential value of hydrogen (pH) is within the norm for subterranean waters store in the pores of limestone rocks since it varies between 8.1 and 8.5, while the biological demand for oxygen varies between 5 and 21 suggesting some low level organic contamination.

4. The Conflict Society Government for the Protection of Water in Los Haitises

On April 15, 2009, when we were consulted regarding as to the pertinence of the installation of a Portland cement plant in the hydro-geological zone of Los Haitises, we publicly stated that according to hydro-geological studies that had been developed by the National Institute for Hydraulic Resources, NIHR (INDRHI as known by its Spanish acronym), in the period 1981-1983, in the National Plan for the Investigation, Utilization and Control of Subterranean Waters, PLANIACAS (Spanish acronym) the region of Los Haitises does not allow any type of industry, and much less a cement plant.

In multiple conferences, interviews and articles that we wrote and published in the year

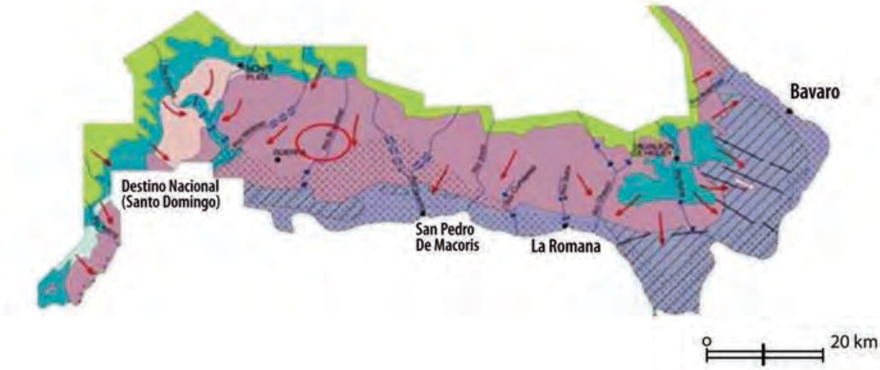


FIG. 2. Simplified Hydrogeological Map (According Aquater, 2000).

2009, we stated that the karstic region of Los Haitises, with a surface area of approximately 1,617 square kilometers, comprises one of the most important geomorphologic landscapes of limestone domes and submerged surface waters in the country and in the world, where the annual rainfall averages some 1,700 millimeters per square meter, and that these waters infiltrate quickly thanks to the high permeability of the limestone rocks and the extensive interconnecting subterranean cavern system.

We stated and wrote in the press, that because of its great uncontaminated subterranean waters reservoirs, the karstic ecosystem of Los Haitises represents the primary alternative for the future water supply for 5 million inhabitants of the city of Santo Domingo and all the country's Eastern zone, and any industrial activity that develops there, especially a cement plant that would exploit the limestone rock through the use of explosives elaborated with an ammonium nitrate and fuel oil base, would quickly contaminate the subterranean water, and that had to be avoided.

Once and again we publicly manifested that due to that reason the cement factory Estrella authorized by the government and the Ministry of the Environment, should be moved to another location, away from Los Haitises, because in the Dominican Republic there are thousands of places that a cement factory can be installed without degrading the subterranean waters while a Gallup poll reflected that 85% of the population rejected the installation of said cement factory.

FIG. 3. Aerial View of the Karstic Region of Los Haitises

In order to detain the installation of the cement factory we interposed an appeal before the Contentious, Tributary and Administrative Court, which was so forceful in its structural analysis that the judge Sarah Henríquez Marín ruled in our favor ordering that all works on the installation of the cement factory be detained, which obligated the President of the Republic, Leonel Fernández, to request from the United Nations Development Program (PNUD Spanish acronym) a technical opinion.

Given the delicate assignment, the PNUD avail itself from the United Nations Development Program for the Environment, PNUMA (Spanish acronym) and from more than a dozen international specialists, whom upon listening to both parties opinion on this regard, including the Academy of Sciences, and having later studied the zone's hydro-geology, concluded in November 2009, that the cement factory project in Los Haitises "WAS NOT VIABLE", which constituted a rotund triumph from a society that confronted the government to protect the quality of its subterranean waters and the people throughout the country went out to the streets to celebrate the rejection of the cement factory.

A year after the PNUD report that rejected the cement factory in Los Haitises, the Executive Director for the National Institute for Hydraulic Resources, INDRHI, engineer Frank Rodriguez, publicly stated that the government had conducted a new hydro-geological investigation in the region of Los Haitises, through the utilization of radioactive isotopic tracers which was carried out with the technical and financial assistance of the International Agency for Energy (AIEA), a United Nations organism with headquarters in Geneva, Switzerland and in coordination with the National Energy Commission.

Frank Rodriguez stated that "The region of Los Haitises has a soil composed primarily of high permeability of limestone rock, that causes water from rainfall infiltrate it almost in its entirety, their circulation in surface sources which therefore to obtain the resource you have to recur to the extraction of subterranean waters". Just as we had said in the year 2009.

He also stated that "The principal finding obtained up until now had been that in that zone any contaminating substance is transmitted quickly, affecting the interconnecting bodies of waters, since the transmission velocity is barely seven hours, which exposes the high vulnerability of the water located in the subsoil". Similar to what we had stated in the year 2009.

But the most important thing that the Director of INDRHI has said is that "These results allows us to affirm that the residual waters from agricultural or livestock activity should be controlled and avoid industrial activities, that bring about serious problems to this unique ecosystem. Any type of intervention or exploitation in this zone would have serious negative consequences on water quality that would extend to the river basins of the Eastern Coastal Plain, the lower part of the Yuna River and part of the Ozama river basin". Similar to what we had stated in the year 2009.

5. Organic Contamination of Surface and Subterranean Waters

In the city of Santo Domingo you can see each that each time a tower, a housing project, a simple house is built, a suburb or an industry is built, no one is concerned with the construction of a sanitary sewer system that collects sewage water and delivers it to a water treatment plant, they simply construct two wells, one next to the other, and the first is used to discharge the water that contains the feces from the toilets to subterranean waters and the second well is used to extract the same subterranean water which we just contaminated with our own sewage and no one says or does a thing before this grave contamination of our most vital natural resource.

Rich residential sectors such as Naco, Piantini, Evaristo Morales, La Julia, Bella Vista, Serallés and Los Cacicazgos, to cite a few, do not have a sanitary sewer system, and its sewage containing fecal coliforms are discharged daily to the subsoil through the filter wells that drain to the same aquifer from where they are extracted, through the wells, the waters that are used, this is to say that all the wealthy people of the city of Santo Domingo brush and bath in the same sewage that had been previously discharge from their bathroom to the subsoil.

Each time someone brings up this issue with the authorities, the response is that a sanitary sewer system to cover the entire capital city would cost 1,500 million dollars that are not available, although the government has invested nearly 2,500 million dollars in the first two phases of the Santo Domingo Metro without this investment having resolved or will resolved the urban transportation problem. It is well known that contaminated water for lack of a sanitary sewer system kills 30 thousand people daily in the entire world and that same contaminated water annually kills 4 million children worldwide with diarrhea of which 1.5 are Hindus.

In Latin America only 6% of the residual waters are properly treated, while the remaining 94% is converted into a source of contamination for surface and subterranean water, which has provoked the comeback of Cholera to the extreme that more than 400 thousand cases have been reported.

Not for nothing is said in vane that man drinks 80% of his diseases, and diseases produced from water result in 25 million deaths annually, of which a third correspond to third world countries such as ours and if there are no more deaths we have to be grateful for the intense use of chlorine as a disinfecting agent of contaminated waters. Perhaps the contamination of our surface and subterranean waters obeys the new private market for water, which annually commercializes nearly 150 billion bottles of purified water, where Italy and France are the lead consumers of this bottled liquid, and perhaps because of that international organisms such as the International Monetary Fund and the World Bank, instead of demanding that emerging nations invest in the construction of sanitary sewage systems, demand and obligate them to privatize water services since water represents big business at present and in the future.

FIG. 4. Contamination of Water by Garbage and Leachates

6. Water and Cholera in the Dominican Republic in 2011

In October 2010, months after the devastating earthquake the sister Republic of Haiti was affected by the Vibrio cholerae bacteria, killing approximately 5,000 persons in just six months.

Since Haiti and the Dominican Republic share the same island of Hispaniola, the permanent frontier migration transported the bacteria to the Dominican Republic where the lack of sanitary sewage systems has led cities such as Santo Domingo to make use of toilet water through filter wells that discharge feces in the same subterranean waters that we capture through drill wells, while poor people that live on the banks, streams and ravines, and generally do not have latrines and defecate outdoors along river banks, contaminate the surface waters with (Vibrio cholerae, Escherichia coli, Salmonella) and in that manner transmit diseases such as Cholera, Salmonella and Amebiasis because the other people in the vicinity use the same contaminated water with the vector that transmits the disease.

The overcrowding along river and stream banks and the proliferation of filter wells in the city of Santo Domingo create adequate conditions for the proliferation of this old water disease and although since October and November 2010 we were warning through the communication media on the Cholera expansion through contaminated was, the authorities underestimated the gravity of the problem and suddenly the country has seen itself severely affected by this epidemic, to the extreme that in the last week of May 2011 the Ministry of Public Health warned that the country's principal rivers are contaminated the Vibrio Cholerae bacteria and that the people should abstain from consuming these water and inclusively abstain from bathing in them.

The bacteria is transmitted through the water, mainly in those places where the absence of latrines the people defecate on river and stream banks and in those place where the non existence of sanitary sewage leads to the construction of filter wells that drain the bacteria from the feces to the same subterranean waters that we used through wells and springs, or where marginal people drain their toilets through a PVC pipe that unloads feces in the neighboring rivers and streams, since for years we have been staying that the lack of sanitary sewage systems, our rivers, streams and ravines have been converted into real urban sewers and that it multiplies the water diseases, which is why it I urgent that we invest resources in the construction of sanitary sewer systems and in the construction of water treatment plants for used water.

Let us remember the Cholera plaque that killed dozens of thousands of people in the city of London in the year 1854, the result of the water from the River Thames which were contaminated by feces from the same London citizens and let us remember the famous Cholera epidemic case in Peru in 1991.

Because the unstoppable advance of Cholera in the Dominican Republic, it is important that the Public Health authorities and the authorities of the ruling institutions that handle water and basic sanitation educate the population on grave health problems caused by the contamination of surface and subterranean waters Vibrio Cholerae bacteria, as the result of the absence of sufficient latrines in marginal zones and the absence of adequate sanitary sewers systems because the reality is that surface and subterranean waters are easily contaminated in those places where there aren't adequate sanitary services.

A person with Cholera that defecates and discharges a toilet can contaminate other people in his surroundings when the liquids from the filter well contaminate the waters capture from the neighboring well.

Government authorities should freely distribute chlorine at all the potential Cholera contamination sources so that people use five drops of chlorine for each gallon of water, or one fourth (1/4) of a liter of chlorine for each thousand gallons of water in a cistern as a form of preventing the disease, especially if the cistern also receives well water. This means that if the cistern stores 2,000 gallons of water you have to pour half a liter of chlorine, but if the cistern stores 4,000 gallons of water you have to pour a liter of chlorine.

7. Dams and their Social and Environmental Conflicts

The construction of dams both in the Dominican Republic as well as in other parts of the world has been occasion of multiple controversies which has given rise to different criteria among preservation ecologists and the environmental followers of sustainable development. The controversy is based on that the human being has received multiple natural resources and should be able to make use of them without deteriorating them, in a fashion that future generations should be able to make use of these same resources in equal

6

NACIONALES

Germán cita compromiso del PLD

Preocupación. El ministro de Salud recorrió varios hospitales del país para cerciorarse de que el protocolo se está cumpliendo

Ríos Ozama e Isabela también están contaminados por cólera

Salud Pública recomienda a moradores aledaños a esas fuentes fluviales no usar aguas

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HEADLINE NEWS: El Dia Newspaper, Monday, May 30, 2011

NATIONAL NEWS, (Inset) German cites the PLD'S commitment: Alejandrina German indicated that in the June 26th primaries the PLD should demonstrate to the population that it is the country's main political force.

Concern: The Minister of Health visited various hospitals throughout the country to insure that the protocol is being complied with.

Ozama and Isabela Rivers are contaminated by Cholera

Public Health recommends inhabitants surroundings these water sources not to use water

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conditions, and that is not always attainable since many times that same human being acts in condition to his needs and present urgencies and completely forgets the future, not because of generational selfishness, but because of social circumstance that he cannot control or bypass.

FIG. 6. The Tavera Dam and its Interconnection with the Bao Dam

And this is where water comes in which is the most special natural resource, since the biological structure of the human being obligates him to depend on absolute terms on fresh water, which represents 2.8% of the total water available on the planet, although only 0.06 % present in the subsoil can be used and of the 0.03% existing in surface sources, the latter being of the easiest access, of the easiest contamination and at the same the one that most quickly reaches the sea if it is not capture beforehand for its utilization.

Once a drop of fresh water reaches the sea it is not longer useable at a lower cost, at least within that hydrological cycle, being necessary to wait for new volumes are evaporated to recharge the clouds and wait for the seasonal rain to replenish rivers, streams and aquifers, but that can be a long wait as it now happens, where the drought threatens the entire Caribbean region, the intense and long fires consume our national parks forest reserves and the uncertainty lies over those who depend on water to produce foods and to satisfy thirst.

Fortunately no one in the Dominican Republic is dying of thirst because the 18 principal dams in the Dominican Republic store 2,200 cubic meters of water, providing potable water to 3 million persons, irrigating 62,000 hectares of land under cultivation and have an available generation capacity of 452 megawatts, that in a year totals some 1,000 giga watts/hour, in other words, a thousand million kilowatts/ hour without the need for petroleum and without contaminating the environment with gases that produce the greenhouse effect, such carbon dioxide (CO_2).

The environmentalist that are knowledgeable about the national dams systems and its surrounding, recognize that the dams that provide society and the environment more benefits than harm, and there is the examples of the Valdesia Dam that supplies 6 cubic meters of water per second (137 million gallons daily) for those living in Santo Domingo; and the dams de Tavera-Bao which contribute 4.5 cubic meters of water per second, equivalent to 103 million gallons daily for the city of Santiago and Moca, although none of these dams were constructed to supply said aqueducts: and despite that these dams were the subject of opposition and harsh criticism at the start of their construction.

Without the Tavera and Valdesia dams, Santo Domingo, Santiago and Moca, would not have water nor would the farmers in Baní, San

Cristóbal and western Cibao have water for irrigating more than 30,000 hectares through the Marcos A. Cabral, Nizao-Najayo and PRYN canals, nor would we be able to avail ourselves of 204 megawatts installed in the hydro-electric turbines of Jiguey-Aguacate-Valdesia, nor of the 100 megawatts installed in the hydro-electric turbines installed in Tavera, without using expensive petroleum and without contaminating the environment. We should prefer the use of water, the sun or the wind to generate electricity instead of costly petroleum and is highly contaminating upon liberating CO, CO_2 and SO_2.

In the same manner the Monción Dam was originally questioned because it would contain the waters from the Mao river, affect the regional flora and displace the peasants from the zone, however today the aqueduct in the northeastern region is a reality thanks to the waters stored in the aforementioned dam, and in the future the results should be more convincing. That is why each drop of water should be stored and rationally managed during dry spells such as we are now experiencing, and that is why it is fundamental to invest in the construction of dams that allow us to store the surplus water from rainfall during the rainy season in order to ration it during periods of long droughts.

Within this idea of producing clean and cheap energy, it is necessary to prioritize the construction of new hydro-electrical centers in the basins of Alto Yaque del Norte, Alto Yaque del Sur, Alto Yuna, and Macasía-Artibonito, with external financing guaranteed by its own production of energy, and design a new plan for the expansion of the national electrical system sustained by non petroleum energy sources, in the protection of the environment and in the growth of the installed capacity directly proportioned to the growing national demand.

Our high basins are protected by the national parks, but protection is not simply for preservation, but to guarantee sustainable development, and the dams guarantee not only the sustainable development of the nation, but also the protection of the very parks themselves because when flames consume the pine forest of the Armando Bermúdez and José del Carmen Ramírez National Parks, it had been necessary to recur to the waters stored en the dam of Sabaneta to supply the helicopters that intend to put out the flames that for weeks remained uncontrollable and had devoured more than 100,000 tareas (628.86m^2) of green pines. Again the dams made their contribution.

8. The Social and Environmental Problem of the Rising of the Waters of Lago Enriquillo

Lake Enriquillo, Lake Sumatra and the Lagoon of Cabral are three lakes remaining from an old marine cannel that communicated the Bay of Neiba with the Bay of Port au Prince, in a geological past in which the Sierra de Bahoruco was a long limestone island separated from the rest of the island of Hispaniola.

The push to the northern side of the micro tectonic plate of Bahoruco, generated compressing effects on the zone of Jimaní and created an intermediate cliff in the form of an anticlinal fold which divided the marine cannel into two large bays, while later tectonic risings of the southern platform and the deposition of large volumes of gravel, sand and clay in the place where the Yaque del Sur River flows into the Bay of Neiba, gradually closed the eastern opening into the marine channel. In this manner the marine channel became two large lakes, one on the eastern side and another on the western side; but the region's high evaporation rate which is in the tune of 2,500 millimeters annually for each square meter, caused the evaporation of the greater part of water from these salt lakes only remaining the water accumulated in the three principal topographical depressions of the region: Enriquillo, Sumatra and Cabral.

Lake Enriquillo receives huge subterranean flows from the springs of Las Barías, in La Descubierta; Boca de Cachón, northeast of Jimaní, La Zurza, to the west of Duvergé; and Las Marías, to the east of Neiba, in the same manner that it receives surface flow from Las Damas, Barreras, Bermesí, Panzo, Guayabal rivers and the irrigation canals from the eastern extreme; all with varying flows depending on the condition of the seasonal rain and in the last two years have totaled more than 1,100 million cubic meters annually.

But Lake Enriquillo because of its deep endoergic basin which today is 36 meters below sea level, can only lose water through the evaporation process, with a surface approximating 300 square kilometers, which is say some 300 million square meters, and each square meter annually evaporates 2,500

FIG. 7. Satellite Images of the Lagoon Caiman (small on the left), the Great Lakes: Sumatra (left), Enriquillo (center), and Laguna Cabral (right). The Image Below, from November 2010, Shows Growth of Lake Enriquillo and Flooding on the West Side.

millimeters or, 2.5 meters of water column, evaporating approximately 750 million cubic meter of water annually, and always when the annual net replenishment is inferior to this value Lake Enriquillo will descend its level, but if the net annual replenishment is superior to 750 million cubic meters, which has been the case in these two years, then the level of the lake will rise and it is going to recuperate the neighboring spaces and lands which have always belong to the lake since long before humans inhabited these inhospitable lands for the first time.

However, the strong rain precipitation fallen over the southwestern region of the country, during the coming of the Noel storm at the end of October 2007, discharged 700 millimeters of rain in barely 5 days, in a valley where average precipitation is in the range of 450 millimeters annually, which provoked a great runoff from the rivers that drain these lakes and a substantial replenishment of the cavernous aquifers of the Neiba and Bahoruco ranges; aquifers that drain underground part of their waters to these lakes: and this, added to the fact that upon opening the storm drains in the dams of Sabaneta and Sabana Yegua for various days, the river flow from Yaque del Sur increased enormously, in some cases up to 350 cubic meters per second, and since for various years a great part of the water from the Yaque River has been deviated towards the Cabral Lagoon and from there it drains towards the eastern portion of Lake Enriquillo, this also contributed to the rise in Lake Enriquillo.

But we have to careful upon saying that the increase in Lake Enriquillo's level is fundamentally due to the contributions from the Yaque del Sur River, to the deterioration of hydraulic Works that serve as avenues of control in the zone and to the entry of large volumes of sediment, since that does not correspond to the regional geological hydro-geological pattern, because if you eliminate or deviate entirely the Yaque del Sur River, the lake would continue to rise in the same proportion that the regional subterranean flow keep rising as a result of the rains that replenish the neighboring aquifers and the best demonstration of all of this is that the last few years Lake Sumatra, which has a height of 15 meter above sea level has risen up to 19 meters above sea level, in other words is has risen 4 meters, as the same as Lake Enriquillo, which has risen from minus 40 meters up to the height of minus 36 meters, and there is no possible manner that the Yaque del Sur river raises its waters up to Lake Sumatra, whose level is still superior to 55 meters higher than Lake Enriquillo.

Also we have to be careful when saying that the sea level is the result of the polar glaciers melting, is responsible for the increase in Lake Enriquillo's level, because if Lake Sumatra and Lake Enriquillo have been rising in equal proportion, how do you explain the increase in Lake Sumatra which today is 19 meters above sea level? How did the level of Lake Sumatra rise?

We should not say that the tectonic regional faults that define Lake Enriquillo's graben allow the water from Lake Sumatra flow underground towards Lake Enriquillo, because the Lake Sumatra would have lowered its level while Lake Enriquillo would have been permanently raising the flow transference level, and what is certain is that both lakes have risen simultaneously.

Always when Lake Enriquillo receives a water flow superior to 750 million cubic meter of water per year its level has risen, and always when Lake Sumatra receives a flow superior to 288 million cubic meters annually its level has risen, indistinctively of any illogical theory that is put forth solely for emitting an opinion.

Lake Enriquillo has always had growth periods tied to meteorological phenomena such as hurricanes and storms which have contributed huge subterranean and surface water flows, and later has had rest periods tied to long regional droughts, but it always recuperates its space.

The solution to Lake Enriquillo's grave regional water problem, which preoccupies the government and the country is to relocate the farmers, cattlemen and the inhabitants of the zone, outside the lake's maximum flood fringe, preferably to the zone el El Limón in Jimaní, and to the zone of Tamayo-Galván, because if you cannot relocate the lake, then relocate the people, because the fluctuations in the lake will continue in a permanent manner.

FIG. 8. Frontier Agricultural Offices Flooded by the Rising Waters of Lake Sumatra, to the West of Jimaní

9. The Problem of Garbage that Contaminates Water

Another serious national problem is the final disposition of our urban and industrial solid wastes (garbage), since our waste are deposited in outside garbage dumps , producing environmental contamination, fires, smells, proliferation of rates and insects, etc.. However, modern tendency is within the planning of land use, is the final disposition of solid urban waste in sanitary landfills constructed over soil which is entirely clayish with the aim of guaranteeing the absolute impermeability of the subsoil and in that manner avoid that the leachates, or contaminating liquids infiltrate and contaminate the subterranean waters since these waters comprise the reserves for future generations and it is necessary to protect them from all type of contamination.

The city of Santo Domingo produces on a daily basis around 3,500 tons of solid waste, of which a third correspond to the National District and two thirds to the province of Santo Domingo, garbage which is made up of largely by paper, cartons, metals, plastic, glass, ceramics, textiles, wood, decomposed vegetables, etc. which should be reclassified, picked up in a timely and effective manner for

FIG. 9. Garbage Dumps in the City of Puerto Plata.

its maximum utilization and those that cannot be reused should be correctly disposed in a sanitary land fill that meets all the existing environmental standards.

On average each citizen produces approximately one kilogram daily of waste, and this permanent generation of solid waste implies a serious environmental contamination problem that should be resolved by encouraging the primary reclassification of garbage in the homes, in businesses, in industries, in schools and medical assistance centers with the goal of minimizing the amount of garbage that requires final disposition and simplifying the correct utilization of the useable portion. It is estimated that there is 45% of organic material (remains from food and gardening), 20% paper and cartons, 15% metallic containers and 20% from other materials. The preference today should be to recycle garbage, an activity that can become a prosperous industry where underprivileged economic communities participate as operators and beneficiaries of the process, while City Hall participates as manager and driver of that same process.

Organic materials are susceptible for the conversion to fertilizer that improve the productivity of the agricultural soil without risking contamination to the soil and subsoil, metals would go to foundries for their low cost reutilization, glass would go to grinding plants for their marketing and reutilization, plastic materials would go to processing plants, and all that cannot be process and taken advantage of would them be deposited in a natural clayish substratum sanitary land fill with the goal that leachates would not contaminate neighboring subterranean waters.

To guarantee the effectiveness of this plan an attempt would be made to get that each home or scholastic establishment have four bins for garbage: one for paper and carton, another for plastic and glass, another, caps, tin sheets, cans, scrap metal, etc. and another for organic waste such as food leftovers; and as special encouragement established that the homes, industries, schools and commercial establishments that reclassify their garbage would pay a rate equal to 50% of the rate to be paid by those who do not classify their garbage, and where the garbage trucks would be outfitted with different compartments for access to for each type of garbage including the non classified ones. The recycling of garbage would generate worthy jobs, improving the quality of life of sectors set apart, it would facilitate that small businessmen could access sources of cheap and renewable raw materials, it would reduce in approximately 75% the final disposal of garbage, it would allow to cover part of the collection and transportation and would significantly reduce the contamination of surface and subterranean waters.

10. The Church, Water and the Environment

On October 21st, 2010 we were invited by the Dominican Episcopate Conference, the Pastorate University and by the Environmental Pastorate to give a main conference in the forum entitled as "Ecology and the Environment: Reality, Challenges and Commitment", to present there a realistic diagnosis of the current environmental in the Dominican Republic.In our dissertation we expressed that the Dominican Republic finds itself today in a real environmental emergency as the result of the high of contamination of surface and subterranean waters product of the irrational management of solid and liquid wastes from residences, homes, industries, hotels, livestock and irresponsible mining.

We demonstrated that Dominican cities lack sanitary sewer systems and for that reason the discharge of raw sewage from residences go to the subsoil through improvised filter wells that drain to the same subterranean waters that we take advantage of through drill wells which produce severe contamination of the subterranean waters with high levels of coliform bacteria, generating multiple gastrointestinal diseases whose treatment is very costly to the Dominican State.

We stated that almost all of the country's rivers have been converted into urban sewers that receive the raw residential and industrial sewage, the acid waters generated by outside mining and a large part of the garbage, and it just suffice to see the high levels of contamination of the Ozama, Isabela, Haina, Margajita, Yuna, Camú, Yaque del Norte, Yaque del Sur, Higüamo and Duey rivers.

We informed that many of the mayorships understood that the best place to deposit garbage was at the .river bank, since in that manner each time that the river rose it would drag the garbage downstream which we classified as barbaric and irrational on behalf of the municipal governments. We emphasized that the absence of a Territorial Land Planning Ordinance was a violation of Art. 30 of Environmental Law 64-00, and that lack of land planning provokes that dozens of thousand of poor people gather at our river banks with which they severely contaminate these waters and expose themselves to the elevated dangers derived from the flooding generated by rains, storms and hurricanes.

We put forth that while reforestation programs are very timid and are concentrated along the sides of highways so that people believe that there is a will to repopulate the forests, the lumber mills have once again multiplied in all of our mountain ranges, although this time they receive the name of forest management plans authorized by environmental authorities and that reduces the rainfall regimen.

We pointed out the that the Ministry of Environment applies an entirely erroneous policy regarding the extraction of aggregated from rivers and rock quarries but sanctions the smaller businesses that apply correct environmental sustainability policy extracting only from the river terrace, above the ground water level and reforesting and leveling the mined soil, while allowing companies that deprecate the riverbeds all types of liberties, opening ground water lagoons to remove aggregates below subterranean water level and contaminate the waters.

We reiterate that the Ministry of Environment behaves as a collecting agency and not like a regulatory agency, and that all this ministry's decisions are contrary to the country's environmental interests, citing as an example the case of the cement plant in Los Haitises and the case of irregular environmental license which supports the Barrick Gold mining company, indicating that in environmental terms the country is not protected.

The conference that was given in the presence of Mons. Agripino Núñez Collado, Rector of the Pontificate Catholic University Mother and Teacher; Rev. Ramón Alonso, Rector of the Catholic University of Santo Domingo, Mons. Nicanor Peña, Bishop for the Diocese of La Altagracia, Rector of the Catholic University of the East and Vice President for the Dominican Episcopate Conference; and Mons. Jesús María de Jesús Moya, Bishop for the Diocese of San Francisco de Macorís and President of the National Commission for the University Pastorate.

There were also present Rev. Francisco Ant. Jiménez R., Secretary General for the Dominican Episcopate Conference and Executive Secretary of the National Commission for the University Pastorate, Rev. Fausto Ramón Mejía, Rector of the Catholic University of the Cibao; Rev. Alfredo de la Cruz, Rector of the Catholic University Nordestana; Rev. José Goris, Rector for the Santo Tomás de Aquino Seminary; Rev. Francisco Escolástico, S.J, Rector of the Specialized Institute for the Loyola Superior Studies and Jovanny Krawinkel, Secretary General for the Ecological Pastorate.

The fact that an important part of the Catholic church hierarchy convoked this important event on Ecology and the Environment, and the fact that the principal bishops committed to the preservation of the Dominican environment and water quality, were present during our conference indicates that the Catholic church feels it is its duty to find the truth on the national environmental situation and desires to keep guard the preservation of our habitat but especially the quality of water that we consume.

FIG.10. Acid Water is Constantly Flowing from the Barrick Gold Installations

11. Water Contamination Due to Mining Operation

In the analysis of acidic waters and loaded with heavy metals coming from the gold and silver mine managed by the mining company Barrick Gold the water's pH is found to be 2.1, the electrical conductivity of water has a value of 4,580 μS/cm, and that the iron content is superior to 2,000 milligrams per liter, which indicates that these waters are contaminating the dam of Hatillo, the country's biggest dam, which stores 440 million cubic meter of water and upon it depends all the rice zone of the lower Yuna, and in the near future the city of Santo Domingo will require near to 8 cubic meters per second from this dam.

Lago Atitlán

State of Water in Guatemala

Manuel Basterrechea

Academia de Ciencias Médicas, Físicas y Naturales

1. Introduction

The Science Academy of Guatemala, interested in contributing to the knowledge of water resources of its country, has elaborated this report which describes the actual situation of water management with its long and medium terms challenges. The report is based on the diagnosis of the water resources of 2007, prepared by the General Secretariat of Planning with the support of the Inter-American Development Bank.

The report's content was design by the "Inter-American Network of Academies of Science", IANAS. One of IANAS purposes is to elaborate a document of the water resources situation of each country of America, coordinated by the national members of the Science Academy and with the participation of key actors.

The methodology used to elaborate the report consisted on: first, elaborate a draft version of the report; second, on a feedback conference, this draft was discussed with people and entities related with the topic; third, the commentaries received on the feedback were included on the report; fourth, the report was sent to the Directive Committee of IANAS for its review and commentaries; fifth, final edition and publication of the report.

The financial support of the Fund for Scientific and Technological Activities - FACYT-, is grateful. The FACYT is a line of the FONACYT, orientated to the financing of activities that strengthen the national scientific and technological development; to the formation and training of the human resource in the scientific and technological field, the stimulation of the creativity and the diffusion and the transfer of technology. Additional, the participation of the members of the Technical Inter-Sectorial Commission of Environment -CIMA-, of the National System of Science and Technology SINACYT and of the Academy of Sciences of Guatemala, is also grateful.

2. Availability and Spatial and Temporal Distribution of Water Resources

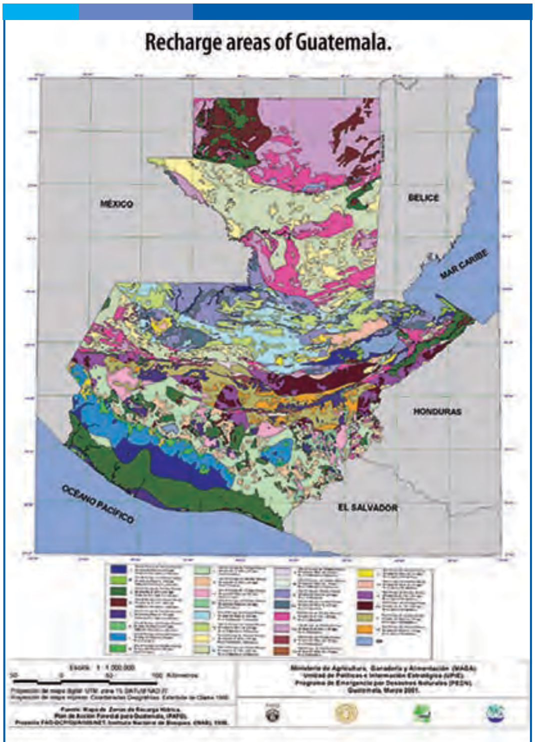
The present map gives details of the water volume available on the country and water available per capita. The per capita data is used to compare with the intensity of water usage or water risk rates. Also, the superficial sources and groundwater reserves are described. The levels of exploitation of the above mentioned sources, both from its basins and of certain areas fastened over-exploitation, are mention as well. Due to its geographic position, Guatemala receives the humid winds that come from the Caribbean Sea and the Pacific Ocean. Also, because of its nearby location to humidity sources, the country precipitation is very intense on the hillsides of the mountains exposed to the traffic of such winds. FIG. 1 shows the geographic location of Guatemala. As a consequence and according to the annual water balances (annual average volumes), the country has a significant amount of water

FIG.1. Geographic Location of the Republic of Guatemala

Source: MAGA, UPIE, Laboratorio de SIG (2001).

FIG.2. Watersheds Map of Guatetmala

exceeding abundantly resource demand. The annual average availability of surface and groundwater is estimated at 97.120 million m^3. The superficial water sources in the country are divided into three hydrographic regions (FIG. 2.) expressed in 38 river basins and 194 inland water bodies.[1] Groundwater in the country have been divided into four hydro-geological regions: (i) quaternary alluvial plains of the South Coast, which are believed to be formations with greater potential for these waters, (ii) the volcanic plateau of tertiary rocks and quaternary tectonic depressions filled with pyro clastic deposits, which form the plateau, with a potential occurrence of such relatively large water depths, (iii) the highland mountain crystalline granite of igneous and metamorphic rocks, which is training with fewer occurrences of the country, and (iv) the Northern region of sedimentary rocks karstified Cretaceous limestone, where groundwater occurs in karst conduits, which despite its importance, its dynamics has been poorly studied.[2] The annual renewable groundwater is estimated at 33.699 million m^3, which are considered within the overall availability of 97.120 million m^3 (FIG. 3.).



Source: MAGA 2001

FIG. 3. Recharge Areas of Guatemala

1 PREPAC (2005): Inventory of inland water bodies of Guatemala, with emphasis on fisheries and aquaculture. 878 pages.

2 Defined by Carlos Muñoz Palacios (1992): Master Plan for Irrigation and Drainage

Despite the annual availability of surface and groundwater, physical evidence such as dry river on the south coast and lakes disappearing in south-east, besides the increase of population demands for better water service especially in the metropolitan area, and growing conflicts over water use in various parts of the country indicate that there are areas and periods of significant deficits. This deficits cannot yet be rightly identified because the national information system haven't produced the required hydrological information consisting of monthly statements, it has only generated average annual balance in 1975 (INDE), 1992 (UNESCO-INSIVUMEH) and 1994 (PLAMAR). Indeed, the fact that the hydrological regime depends solely on rain and underground storage, plus the average rainfall occurs in six months, makes a significant difference on the rivers flow between the rainy and the dry period. Table 1 and Table 2 show the availability of water (liter / capita / day) annual national and for the driest month.

Table 1. Annual Water Availability (National and by Drainage Basin)

Drainage Basin	Area (km²)	% area	Q_{medium} (m³/s)	Q (liters/s/km²)	Population (2002)	% People	% People/km²	liters/People/day
Pacific Ocean	23,990	22.0	728.47	31	5,897,817	52.5	245.8	10,897
Caribbean Sea	34,259	31.5	1,180.53	34	3,450,840	30.7	100.7	30,030
Gulf of Mexico	50,640	46.5	1,297.63	26	1,888,539	16.8	37.3	60,225
Total	108,889	100.0	3,206.63	29	11,237,196	100.0	103.2	25,116

Source: SEGEPLAN (2007).

Table 2. Water Availability in the Dry Season Months (National and by Drainage Basin)

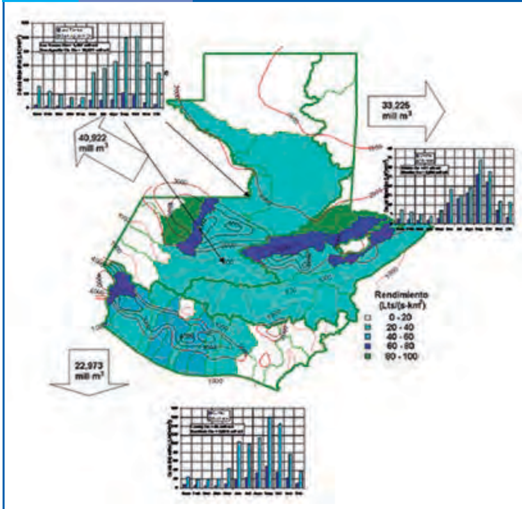
Drainage Basin	Area (km²)	% area	Q_{medium} (m³/s)	Q (liters/s/km²)	Population (2002)	% People	% People/km²	liters/People/day
Pacific Ocean	23,990	22.0	291.39	12	5,897,817	52.5	245.8	4,218
Caribbean Sea	34,259	31.5	354.16	10	3,450,840	30.7	100.7	8,580
Gulf of Mexico	50,640	46.5	402.27	8	1,888,539	16.8	37.3	18,531
Total	108,889	100.0	1,047.81	10	11,237,196	100.0	103.2	8,372

Source: SEGEPLAN (2007).

The annual returns on the month of drought in each of the sides are proportional, because there are wet lands and dry lands. However, the slope of the Gulf of Mexico has more per capita availability because of the lower population density and greater volume flow. When comparing the annual per capita availability, the Gulf of Mexico is 6 times higher than the Pacific and 2 times higher than the Caribbean Sea in the driest month, the ratio is 4 and 2 times in the annual bases, respectively.

Moreover, a country with an availability greater than 1,000 m^3 / capita / year (2.740 liters / capita / day) is considered that there is no risk of flooding, which occurs in all cases. Moreover, the spatial distribution of rainfall is very irregular and natural water availability does not exactly match the demands. In regions located in the upper parts of watersheds and receiving less precipitation, the occurrence of water as surface flow is lower and there is where most of the country population sits; which is the case of metropolitan area of Guatemala, 10 of the 22 departmental most populous capitals of the country and more than 130 of the 335 municipal seats.

FIG. 4 shows the annual average rainfall of the country (isohyets), the variation of monthly mean flows at two stations for each of the three areas and yields and surface water availability by watershed.



Source: SEGEPLAN (2007).

FIG. 4. Availability & Temporal and Spatial Distribution of Water in the Country.

3. Water Balance 2005

Table 3 shows that the country has a 97.120 million m^3 supply or availability of raw water, distributed as follows: 23.7% in the Pacific Ocean side, 42.1% in the Gulf of Mexico, and 34.2 % remaining in the Caribbean Sea. Of the water supply, 23.3%, 4.4% and 7.4% in each of the basin respectively, are demanded; involving a use of 9.9% nationwide. This shows that the Gulf of Mexico is the watershed with most water and with less demand, contrary to what happens in the Pacific Ocean watershed (reduced availability, increased demand). The first user of water should be the ecological flow (10% of average annual flow), but does not currently apply in the country, so it was not considered in the balance. The country uses 9.596 million m^3 of water, 53.6% for consumptive uses and the remaining 46.4% in non-consumptive. At a more disaggregated, it could be said that of this total, hydro uses a 46.4%, 8.7% for human consumption, irrigation 38.2%. By taking into account only consumptive uses, water used for human consumption 16.2%, 76.9% irrigation and industry 6.7%, and other users consume the remaining 0.2%.

Table 3. Water Balance of 2005 (National and by Drainage Basin)

		Supply and annual water use in Guatemala				Situation for the driest month			
Concept	Indicators	DB Pacific Ocean	DB Gulf of Mexico	DB Caribbean Sea	Total Country	DB Pacific Ocean	DB Gulf of Mexico	DB Caribbean Sea	Total Country
	flow (m^3/seg)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)
I. Water Capital	**3,079.65**	**22,973.03**	**40,922.06**	**33,224.75**	**97,119.84**	**755.28**	**1,042.67**	**846.55**	**2,644.50**
Drainage Basin of Pacific Ocean	728.47								
Drainage Basin of Gulf of México	1,297.63								
Drainage Basin of Caribbean Sea	1,053.55								
II. Total consumptive or non-consumptive demands		**5,346.23**	**1,783.46**	**2,466.37**	**9,596.06**	**698.19**	**159.59**	**277.00**	**1,134.78**
III. Total consumptive demands		**3,758.73**	**278.83**	**1,105.07**	**5,142.63**	**565.90**	**34.21**	**163.56**	**763.66**
a. Water supply and sanitation	Households Country	485.22	132.50	216.90	834.62	40.43	11.04	18.08	69.55
Households with home service	1,458,480	426.96	112.82	191.71	731.48	35.58	9.40	15.98	60.96
Households with community service	182,537	31.11	5.24	13.02	49.37	2.59	0.44	1.09	4.11
Households with other services (water well)	337,241	22.44	10.90	7.37	40.71	1.87	0.91	0.61	3.39
Households without service (poor access)	222,350	4.70	3.54	4.81	13.06	0.39	0.30	0.40	1.09
	2,200,608								
b. agricultural use		2,977.06	130.41	849.62	3,957.09	500.76	21.84	142.27	664.86
Irrigation (312 000 ha in the Country)		2,743.62	123.03	801.53	3,668.18	457.27	20.51	133.59	611.36
Livestock and other agricultural uses (2.0 millons UA)		27.44	1.23	8.02	36.69	2.29	0.10	0.67	3.06

Concept	Supply and annual water use in Guatemala: Indicators	DB Pacific Ocean	DB Gulf of Mexico	DB Caribbean Sea	Total Country	Situation for the driest month: DB Pacific Ocean	DB Gulf of Mexico	DB Caribbean Sea	Total Country
	flow (m^3/seg)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)
Agroindustrial (washing cane and other)		206.00	6.15	40.08	252.23	41.20	1.23	8.02	50.45
c. Industry and other processing activities		291.28	13.84	37.51	342.63	24.27	1.15	3.13	28.55
Manufacturing (80m^3/USD1000 VA)		285.28	11.84	35.51	332.63	23.77	0.99	2.96	27.72
Construction industry		6.00	2.00	2.00	10.00	0.50	0.17	0.17	0.83
d. Mining		0.00	0.60	0.30	0.90	0.00	0.05	0.03	0.08
Gold Mines - Marlín	822 m^3/ day	0.00	0.30	0.00	0.30	0.00	0.03	0.00	0.03
Other mines and other mining products (estimation)		0.00	0.30	0.30	0.60	0.00	0.03	0.03	0.05
e. Other economic activities		5.18	1.48	0.74	7.40	0.43	0.12	0.06	0.62
Hotels and Restaurants (27,038 availability of beds per day. 50%)		3.45	0.99	0.49	4.93	0.29	0.08	0.04	0.41
Commerce and others		1.73	0.49	0.25	2.47	0.14	0.04	0.02	0.21
IV. Total non-consumptive demands		**1,587.50**	**1,504.63**	**1,361.30**	**4,453.43**	**132.29**	**125.39**	**113.44**	**371.12**
Hydropower	141.21	1,587.33	1,504.63	1,361.30	4,453.26	132.28	125.39	113.44	371.11
- Drainage Basin of Pacific Ocean	50.33								
- Drainage Basin of Gulf of México	47.7								
- Drainage Basin of Caribbean Sea	43.17								

Concept	Indicators	Supply and annual water use in Guatemala: DB Pacific Ocean	DB Gulf of Mexico	DB Caribbean Sea	Total Country	Situation for the driest month: DB Pacific Ocean	DB Gulf of Mexico	DB Caribbean Sea	Total Country
	flow (m^3/seg)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)
Thermal Energy (Except cogenerators mills)	3910 mill kv/h	0.17	0.00	0.00	0.17	0.01	0.00	0.00	0.01
V. Irrigation return water (infiltration)		**1,097.45**	**49.21**	**320.61**	**1,467.27**	**182.91**	**8.20**	**53.44**	**244.55**
VI. Generation contaminated water		**1,060.93**	**137.63**	**340.90**	**1,539.46**	**129.57**	**13.31**	**40.43**	**183.31**
Domestic origin		388.17	106.00	173.52	667.69	32.35	8.83	14.46	55.64
Agricultural origin		493.85	22.15	144.28	660.27	82.31	3.69	24.05	110.05
Industrial origin		174.77	8.30	22.51	205.58	14.56	0.69	1.88	
Origin of other economic activities		4.14	1.18	0.59	5.92	0.35	0.10	0.05	0.49
Balance (surplus or deficit)		**21,372.6**	**40,830.07**	**32,781.1**	**94,983.94**	**501.86**	**1,029.98**	**776.86**	**2,308.70**

Source: SEGEPLAN (2007).

Of all the water used in the country, 1.540 million m^3 of wastewater is generated (only 5% are treated), generally discharged untreated into surface streams or bodies of water, so that automatically limit or hinder subsequent uses. Additionally, 40% of water used in irrigation returns to the rivers to infiltrate.

Given the country's water capital and total consumptive demands, there's an original surplus of 87.524 million m^3; to this the volumes of non-consumptive use, the contaminated water and of return are added, giving an annual balance of 94.984 million m^3. This, for lack of sewage treatment and inability of the sources of pollution fully diluted, become low-quality water available. The previous balance indicates a relationship between balance and availability of 0.98.

As shown in Table 3, in the month of dry season of 2005 there's a surplus of 2.309 million m^3 at the national level, reducing the balance-capital ratio to 0.87. Doing the analysis, as in the previous case (an annual report), it follows that there is a total demand of 42.9% available. Pacific Ocean side, as mentioned above, has the highest water demand, also makes use of the available 92.4% in this region, while the Gulf of Mexico, only 15.3% and in 32.7% of the Caribbean Sea. The data show that the water capital of the Pacific watershed, 74.9% is used for consumption, 17.2% for energy producing sector, implying a balance of 7.9%. However, adding water use non-consumptive, contaminated water and irrigation return, the availability of low quality water increases, and obtained a surplus of 66.4% of the available at the beginning of the month.

4. Water Balance and Scenarios to 2025

Throughout this section the projected demand for the various uses of water in 2025, and the water balance is described. For each of the sector water uses, according to growth rates, an estimate demand was projected for the year 2025; there are three possible scenarios: optimistic, pessimistic and normal trend. Table 4 shows the conditions that define each scenario, while growth in demand for applications in each scenario is shown in Table 5. Taking into account that there is not enough information for the preparation of monthly water balance, due to the discontinuity of hydrometric and meteorological stations in time and physical location, making it necessary to reinstall and give continuity to the operation of the few stations ("strategic") that it will have, but they belong to different entities, so it is advisable to consolidate the information into a single institution like the INSIVUMEH or INDE.

The following is a description of the water demand by 2025 from baseline scenario, and Table 6 shows the calculations used to determine the water balance. For domestic use demand, the information was available at the National Institute of Statistics on population projections 2000-2020, following the trend for 2020 was projected for 2025.

For projection data service coverage to the report on the implementation of the Millennium Development Goals (targets 10 and 11, SEGEPLAN 2005), was extended for 2025. The same endowments and efficiency data contained in this report were undertaken, to estimate the current demand (2005).

Table 4. Terms Those Define the Different Scenarios

Conditions/Scenarios	Optimistic	Pessimistic	Normal Trend
Gross domestic product (GDP)	› 5.4 %	‹ 3%	3.6%
Growth of tourism	›8%	‹ 5%	5%
Increased demand AP	›25%	‹ 15%	15%
Increased demand for irrigation	Doubling	little	Increases
Increased technification sprinkler and drip irrigation	Yes	No	No significant
Source: SEGEPLAN (2007).			

Table 5. Annual Growth Rates of the Water Demand Uses for Each Scenario

Growth rates/Scenarios	Optimistic	Pessimistic	Normal Trend
Drinking water	4.7%	4.3%	4.5%
Irrigation	4.1%	2.6%	3.2%
Industry	4.8%	2.3%	2.4%
Energy	4.5%	1.7%	2.5%
Water pollution	1.9%	3.1%	2.6%
Reduction return water by irrigation efficiency	25.0%	0%	0%

Source: SEGEPLAN (2007).

In the case of irrigation water was considered that for the next 20 years, following the trend of the past 20 years, the country will double the area under irrigation, improving the proportion of lower-power systems such as irrigation sprinkler and drip.

An expansion was made in the case of industry, assuming a growth rate of this economic activity of 2.5% annually, a figure that may seem conservative given the expectation that it could generate the validity of the new trade and investment treaties it has signed the country but also takes into account that the new models of investment in industries with technology will be greater savings of inputs, including water. The same annual growth rate was estimated to calculate the water demand of the other branches of economic activity, this could be short for the case of hotels and tourism if the country is to position and expand their strengths and attributes in the development of inbound tourism.

Human Consumption: For 2025 it is estimated that Guatemala will have a total of 19.96 million inhabitants, 7.26 million more than in 2005, equivalent to 4.0 million homes. In the Pacific watershed will be 9.4 million people, 4.5 million in the Gulf of Mexico and 6.1 million in the Caribbean Sea. The rate of piped water coverage is estimated at 86.5% nationally, with 90% for urban areas and 84.2% for rural areas. In these circumstances it is estimated that water demand for domestic use will be 2.010 million m^3 distributed into 57.7% for the Pacific watershed, 14.8% for the Gulf of Mexico and 27.4% for the Caribbean Sea.

Irrigation: In the case of irrigation, water demand by 2025 is estimated at 7.410 million m^3, also the highest demand will focus on the Pacific watershed where the best farmland of the country is located, although given irrigation potential in the department of Petén, many new areas of irrigation in soils with some limitations will be established in that department.

Table 6. Water balance – Normal Trend (estimated for 2025, national and by Drainage Basin

	Supply and annual water use in Guatemala					Situation for the driest month			
	Indica-tors	DB Pacific Ocean	DB Gulf of México	DB Cari-bbean Sea	Total Country	DB Pacific Ocean	DB Gulf of México	DB Cari-bbean Sea	Total Country
Concept	flow (m³/seg)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)
I. Water Capital	**3,079.65**	**22,973.03**	**40,922.06**	**33,224.75**	**97,119.84**	**755.28**	**1,042.67**	**846.55**	**2,644.50**
Drainage Basin of Pacific Ocean	728.47								
Drainage Basin of Gulf of México	1,297.63								
Drainage Basin of Caribbean Sea	1,053.55								
II. Total consumptive or non-consumptive demands		**10,123.51**	**3,048.95**	**4,623.60**	**17,796.06**	**1,340.15**	**276.00**	**537.63**	**2,154.13**
III. Total consumptive demands		**7,522.19**	**583.44**	**2,392.95**	**10,498.58**	**1,123.38**	**70.54**	**351.74**	**1,546.01**
a. Water supply and sanitation	House-holds Country	1,160.57	297.81	551.65	2,010.03	96.71	24.82	45.97	167.50
Households with home service	3,286,387	1,114.59	269.37	517.04	1,901.00	92.88	22.45	43.09	158.42
Households with community service	212,727	30.73	11.12	17.09	58.94	2.56	0.93	1.42	4.91
Households with other services (water well)	329,165	11.19	13.33	13.33	37.85	0.93	1.11	1.11	3.15
Households with-out service (poor access)	215,811	4.07	3.99	4.19	12.25	0.34	0.33	0.35	1.02
	4,044,091								
b. agricultural use		5,879.67	260.82	1,779.41	7919.89	986.62	43.67	300.57	1,330.87
Irrigation (312,000 ha in the Country)		5,487.25	246.06	1,603.07	7336.37	914.54	41.01	267.18	1,222.73
Livestock and other agricultural uses (2.0 millons UA)		54.87	2.46	16.03	73.36	4.57	0.21	1.34	6.11
Agroindustrial (washing cane and other)		337.55	12.30	160.31	510.16	67.51	2.46	32.06	102.03

	Supply and annual water use in Guatemala					Situation for the driest month			
	Indicators	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country
Concept	flow (m^3/seg)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)
c. Industry and other processing activities		473.46	21.40	60.19	555.05	39.46	1.78	5.02	46.26
Manufacturing (80m^3/ USD1000 VA)		467.46	19.40	58.19	545.05	38.96	1.62	4.85	45.42
Construction industry		6.00	2.00	2.00	10.00	0.50	0.17	0.17	0.84
d. Mining		0.00	0.98	0.49	1.47	0.00	0.10	0.10	1.51
Gold Mines - Marlín	822 m^3/ día	0.00	0.49	0.00	0.49	0.00	0.03	0.03	0.00
Other mines and other mining products (estimation)		0.00	0.49	0.49	0.98	0.00	0.08	0.08	0.16
e. Other economic activities		8.49	2.43	1.22	12.13	0.59	0.17	0.08	0.84
Hotels and Restaurants (27,038 availability of beds per day. 50%)		5.66	1.62	0.81	8.09	0.47	0.13	0.07	0.67
Commerce and others		2.83	0.81	0.41	4.04	0.12	0.03	0.02	0.17
IV. Total non-consumptive demands		**2,601.31**	**2,465.51**	**2,230.65**	**7,297.47**	**216.77**	**205.46**	**185.89**	**608.12**
Hydropower	141.21	2,601.02	2,465.51	2,230.65	7,297.18	216.75	205.46	185.89	608.10
Drainage Basin of Pacific Ocean	50.33								
Drainage Basin of Gulf of México	47.71								
Drainage Basin of Caribbean Sea	43.17								
Thermal Energy (Except cogenerators mills)	3910 mill kv/h	0.29	0.00	0	0.29	0.01	0.00	0.00	0.01

		Supply and annual water use in Guatemala				Situation for the driest month			
	Indicators	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country
Concept	flow (m³/seg)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)
V. Irrigation return water (infiltration)		**2,194.90**	**98.42**	**641.23**	**2,934.55**	**365.82**	**16.40**	**106.87**	**244.55**
VI. Generation contaminated water		**1,744.49**	**217.56**	**594.87**	**2,556.92**	**219.45**	**21.45**	**71.21**	**312.12**
Domestic origin		649.92	166.77	308.92	1,125.61	54.16	13.90	25.74	93.80
Agricultural origin		888.93	39.86	259.70	1,188.49	148.16	6.64	43.28	198.08
Industrial origin		198.85	8.99	25.28	233.12	16.57	0.75	2.11	19.43
Origin of other economic activities		6.79	1.94	0.97	9.70	0.57	0.16	0.08	0.81
Balance (surplus or deficit)		**19,390.23**	**40,654.60**	**32,067.90**	**92,112.73**	**217.17**	**1,009.98**	**672.89**	**1,655.16**

Source: SEGEPLAN (2007).

Industry: As already indicated, the projection of industrial consumption was under the assumption of an annual growth rate of 2.5%, and consequently the water demand for this sector is estimated at 555 million m³, for the phenomenon location, most of this demand is also concentrated in the Pacific watershed, although several industrial complexes expect high demand for water to move the department of Guatemala to places fewer restrictions on this resource, as is happening in the Pacific coastal plain, close to Puerto Quetzal Escuintla and in the region of Teculután in Zacapa.

Mining: It has been assumed that mining would have a similar behavior as the industry, under which Guatemala has gestated in public opposition to the development of the sector, any investment in this area is subject to make use of good practice environmental and perhaps improve the royalty rates that currently prevail. It has been estimated an annual demand of 1.5 million m ³.

Tourism and Other Services: A conservative forecast has been done for these sectors by assuming growth rates in water demand similar to the behavior of the industrial sector, which means that by 2025 demand will be 12.1 million m ³.

Energy: The country has a tendency to favor investment in hydroelectric, from the standpoint of the public sector, however, much of civil society has formed a popular front against the establishment of such investments in that game interests and pressure groups emerge the need to cover the increased energy demands of society and economy, whose annual demand is estimated to grow by 7% (110 MW). For the calculation of water demand in this sector has been considered by 2025 hydropower will cover a cumulative annual rate of 2.5% of annual increase in energy needs for the country. In that sense this non-consumptive use of water is estimated at 7.297 million m^3.

Balance: The water balance projected to 2025, part of a water supply or capital, assuming no significant changes in spatial distribution of water in the country. In this regard, the offer or gross availability of water equivalent to 97,119.8 million m^3, distributed at 23.7% on the Pacific watershed, 42.2% in the Gulf of Mexico and 34.28% in the Caribbean Sea.

The demand for all consumptive and non consumptive uses in 2025 in baseline was estimated at 17.796 million m^3, including consumptive use reaches 10.499 million m^3 and the demand for non-consumptive use is estimated at 7.298 million m3. Hydroelectricity would use 41.0% of total estimated water usage in the country, for human consumption would go up 11.3%, 44.5% in irrigation, the remaining uses would consume 3.2%. According to data from consumptive use, human consumption used for 19.1%, 75.5% irrigation and industry 5.3%, and other uses will consume the remaining 0.1%. The consumption of previous volumes of water will generate a total of 2.557 million m^3 of contaminated water in the country, with the consequences that this situation represents a volume of irrigation return waters of 2.935 million m^3.

By relating the net annual water availability in the country of 97.120 million m3 with the amount of consumptive demands, described earlier, would reflect a surplus of 92.113 million m^3. By 2025, a 10% of the average flow for each side, would be expected to be an ecological flow, as the first natural water user, so that when subtracted from the gross or capital water supply there will be a net availability of 87.408 million m^3 of water for different users, and the surplus will be 82.401 million m^3.

In the pessimistic scenario, Table 7, surplus by 2025 without considering the ecological flow, will be 92,932 million m^3 and for the optimistic scenario, Table 8, the surplus will be 90,348 million m^3.

In the dry season, the situation could be difficult for the Pacific watershed for any of the scenarios, since 2025 the driest month of the year could be found in the following scenario: water supply or capital is 755 million m 3 and if we discount the ecological flow will be 566 million m^3, the consumptive use will reach 1.056 million m^3, which means a water deficit of 301 or 490 million m^3 (without and with ecological flow). Water use for electricity generation will require 217 million m^3; will generate 379 million m^3 of contaminated water, which would mean that at some points of river water runs into rivers are almost sewage.

The watershed of the Caribbean Sea in 2025 also show moderately difficult situation, because in the driest month of the year as a consumptive use 320 million m³ which represents 56% of available water (573.47 million m³ less the ecological flow), if we add the non-consumptive water requirement for power generation would be consuming 88.2% of available water in that watershed. The watershed of the Gulf of Mexico in 2025 show a situation manageable because the demands of the different uses represent about 25% of water supply.

Due to the non uniformity of temporal and spatial distribution of water, poor quality and lack of governance, we conclude that there is a water risk, Lake Amatitlan being an example. It should motivate the hydrological study that includes the ecological flow with proper weighting for each ecosystem, but more important is to create planning units, watershed level and / or micro, so the same should be institutionalized. There have been no efforts to collect rain water or wastewater treatment. In general, there is no advocacy work to reduce the risk of flooding in places where pollution occurs. There is not a general understanding, nor is invested in environmental education, so they should be socializing for people to take charge of their own projects.

Because of climate change, the availability of water can´t be predicted, but the uses and enhancing will be maintained.

Table 7. Water Balance - Pessimistic Trend (Estimated for 2025)

	Supply and annual water use in Guatemala					Situation for the driest month			
	Indicators	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country
Concept	flow (m^3/seg)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)
I. Water Capital	**3,079.65**	**22,973.03**	**40,922.06**	**33,224.75**	**97,119.84**	**755.28**	**1,042.67**	**846.55**	**2,644.50**
Drainage Basin of Pacific Ocean	728.47								
Drainage Basin of Gulf of México	1,297.63								
Drainage Basin of Caribbean Sea	1,053.55								
II. Total consumptive or non-consumptive demands		**9,149.32**	**2,655.34**	**4,107.38**	**15,912.03**	**1,340.15**	**241.01**	**479.39**	**2,154.13**
III. Total consumptive demands		**6,926.77**	**548.86**	**2,201.56**	**9,677.18**	**1,123.38**	**65.47**	**320.57**	**1,546.01**
a. Water supply and sanitation	Households Country	1,139.04	290.01	539.68	1,968.72	94.92	24.17	44.97	164.06

	Supply and annual water use in Guatemala					Situation for the driest month			
	Indica-tors	**DB Pacific Ocean**	**DB Gulf of México**	**DB Cari-bbean Sea**	**Total Country**	**DB Pacific Ocean**	**DB Gulf of Mé-xico**	**DB Cari-bbean Sea**	**Total Country**
Concept	flow (m^3/seg)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)
Households with home service	3,286.387	1,089.90	258.26	501.65	1,849.80	90.82	21.52	41.80	154.15
Households with community service	212.727	29.95	10.45	16.36	56.76	2.50	0.87	1.36	4.73
Households with other services (water well)	329.165	14.06	16.39	16.48	46.93	1.17	1.37	1.37	3.91
Households without service (poor access)	215.811	5.13	4.91	5.19	15.23	0.43	0.41	0.43	1.27
	4,044.091								
b. agricultural use		5,317.51	234.73	1,601.47	7,153.71	893.12	39.30	270.52	1,202.95
Irrigation (312,000 ha in the Country)		4,938.52	221.45	1,442.76	6,602.73	823.09	36.91	240.46	1,100.46
Livestock and other agricultural uses (2.0 millons UA)		49.39	2.21	14.43	66.03	4.12	0.18	1.20	5.50
Agroindustrial (washing cane and other)		329.6	11.07	144.28	484.95	65.92	2.21	28.86	96.99
c. Industry and other processing activities		462.45	20.94	58.82	542.21	38.54	1.75	4.90	45.19
Manufacturing (80m^3/USD1000 VA)		456.45	18.94	56.82	532.21	38.04	1.58	4.74	44.35
Construction industry		6.00	2.00	2.00	10.00	0.50	0.17	0.17	0.84
d. Mining		0.00	0.96	0.48	1.44	0.00	0.10	0.10	1.51
Gold Mines - Marlín	822 m^3/día	0.00	0.48	0.00	0.48	0.00	0.03	0.03	0.00
Other mines and other mining products (estimation)		0.00	0.48	0.48	0.96	0.00	0.08	0.08	0.16

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	Supply and annual water use in Guatemala					Situation for the driest month			
	Indicators	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country
Concept	flow (m^3/seg)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)
Gold Mines – Marlín	822 m^3/día	0.00	0.48	0.00	0.48	0.00	0.03	0.03	0.00
e. Other economic activities		7.77	2.22	1.11	11.10	0.54	0.15	0.08	0.77
Hotels and Restaurants (27,038 availability of beds per day. 50%)		5.18	1.48	0.74	7.40	0.43	0.12	0.06	0.61
Commerce and others		2.59	0.74	0.37	3.70	0.11	0.03	0.02	0.16
IV. Total non-consumptive demands		**2,222.55**	**2,106.48**	**1,905.82**	**6,234.85**	**185.20**	**175.54**	**158.82**	**519.56**
Energía hidráulica	141.21	2,222.26	2,106.48	1,905.82	6,234.56	185.19	175.54	158.82	519.55
Energía térmica (excepto ingenios cogeneradores)	3910 mill kv/h	0.29	0.00	0.00	0.29	0.01	0.00	0.00	0.01
V. Irrigation return water (infiltration)		**1,975.41**	**88.58**	**577.1**	**5,641.09**	**329.23**	**14.76**	**96.18**	**244.55**
VI. Generation contaminated water		**1,920.53**	**259.77**	**667.93**	**2,848.23**	**230.42**	**24.80**	**76.22**	**331.44**
Domestic origin		820.10	208.81	388.57	1,417.48	68.34	17.40	32.38	118.12
Agricultural origin		844.49	37.87	246.71	1,129.07	140.75	6.31	41.12	188.18
Industrial origin		249.72	11.31	31.76	292.79	20.81	0.94	2.65	24.40
Origin of other economic activities		6.22	1.78	0.89	8.89	0.52	0.15	0.07	0.74
Balance (surplus or deficit)		**19,942.20**	**40,721.55**	**32,268.22**	**95,931.98**	**217.17**	**1,016.77**	**698.38**	**1,655.16**

Source: SEGEPLAN (2007).

Table 8. Water Balance – Optimistic Trend (Estimated for 2025)

	Supply and annual water use in Guatemala					Situation for the driest month			
	Indicators	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country
Concept	flow (m^3/seg)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)
I. Water Capital	**3,079.65**	**22,973.03**	**40,922.06**	**33,224.75**	**97,119.84**	**755.28**	**1,042.67**	**846.55**	**2,644.50**
Drainage Basin of Pacific Ocean	728.47								
Drainage Basin of Gulf of México	1,297.63								
Drainage Basin of Caribbean Sea	1,053.55								
II. Total consumptive or non-consumptive demands		**12,864.89**	**4,271.82**	**6,070.37**	**23,207.08**	**1,670.93**	**382.19**	**688.60**	**2,741.72**
III. Total consumptive demands		**9,055.01**	**660.71**	**2,803.25**	**12,518.97**	**1,353.45**	**81.26**	**416.34**	**1,851.05**
a. Water supply and sanitation	Hogares país	1,200.30	306.58	569.44	2,076.32	100.03	25.55	47.45	173.03
Households with home service	3,286.387	1,158.92	280.17	537.67	1,976.76	96.58	23.35	44.81	164.73
Households with community service	212.727	31.95	11.57	17.77	61.29	2.66	0.96	1.48	5.11
Households with other services (water well)	329.165	7.02	11.47	10.74	29.23	0.59	0.96	0.90	2.44
Households without service (poor access)	215.811	2.41	3.37	3.26	9.04	0.20	0.28	0.27	0.75
	4,044.091								
b. agricultural use		7,083.15	312.98	2,135.29	9,531.42	1,189.46	52.41	360.69	1,602.55
Irrigation (312 000 ha in the Country)		6,584.70	295.27	1,923.68	8,803.65	1,097.45	49.21	320.61	1,467.28
Livestock and other agricultural uses (2.0 millons UA)		65.85	2.95	19.24	88.04	5.49	0.25	1.60	7.34
Agroindustrial (washing cane and other)		432.60	14.76	192.37	639.73	86.52	2.95	38.47	127.94

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	Supply and annual water use in Guatemala					Situation for the driest month			
	Indicators	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country
Concept	flow (m³/seg)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)	volume (mill m³)
c. Industry and other processing activities		747.73	32.78	94.34	874.85	62.31	2.73	7.86	72.90
Manufacturing (80m³/USD1000 VA)		741.73	30.78	92.34	864.85	61.81	2.56	7.69	72.06
Construction industry		6,00	2,00	2,00	10,00	0,50	0,17	0,17	0,84
d. Mining		0.00	1.56	0.78	2.34	0.00	0.10	0.10	1.51
Gold Mines - Marlín	822 m³/día	0.00	0.78	0.00	0.78	0.00	0.03	0.03	0.00
Other mines and other mining products (estimation)		0.00	0.78	0.78	1.56	0.00	0.08	0.08	0.16
e. Other economic activities		23.83	6.81	3.40	34.04	1.65	0.47	0.24	2.36
Hotels and Restaurants (27,038 availability of beds per day. 50%)		15.89	4.54	2.27	22.70	1.32	0.38	0.19	1.89
Commerce and others		7.94	2.27	1.13	11.34	0.33	0.09	0.05	0.47
IV. Total non-consumptive demands		**3,809.88**	**3,611.11**	**3,267.12**	**10,688.11**	**317.48**	**300.93**	**272.26**	**890.67**
Energía hidráulica		141.21	3,809.59	3,611.11	3,267.12	317.47 10,687.82	300.93	272.26	890.66
Energía térmica (excepto ingenios cogeneradores)	3910 mill kv/h	0.29	0.00	0.00	0.29	0.01	0.00	0.00	0.01
V. Irrigation return water (infiltration)		**2,633.88**	**118.11**	**769.47**	**3,521.46**	**438.98**	**19.68**	**128.25**	**586.91**

	Supply and annual water use in Guatemala					Situation for the driest month			
	Indicators	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country	DB Pacific Ocean	DB Gulf of México	DB Caribbean Sea	Total Country
Concept	flow (m^3/seg	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)	volume (mill m^3)
VI. Generation contaminated water		**1,550.79**	**174.43**	**500.84**	**2,226.06**	**198.37**	**17.64**	**61.94**	**277.94**
Domestic origin		480.12	122.63	227.78	830.53	40.01	10.22	18.98	69.21
Agricultural origin		829.67	37.20	242.38	1,109.25	138.28	6.20	40.40	184.88
Industrial origin		224.32	9.83	28.30	262.45	18.69	0.82	2.36	21.87
Origin of other economic activities		16.68	4.77	2.38	23.83	1.39	0.40	0.20	1.99
Balance (surplus or deficit)		**18,102.69**	**40,553.89**	**31,691.81**	**90,348.39**	**39.18**	**998.73**	**620.39**	**1,658.30**

Source: SEGEPLAN (2007).

5. Water and Agriculture

MAGA's Master Plan Study on Irrigation and Drainage (1992) identified that 26 thousand square kilometers (2.6 million hectares) of farmland in the country (agrologic classes I to IV) could be irrigated, which show rainfall deficit (classes rain deficit 1 to 4), as stated in Table 9. The greatest potential lies in the watershed of the Gulf of Mexico (44.7%), precisely where there is greater availability of water in the country, but where there is less population pressure and agricultural activity is extensive and least developed character on the practice in the other tracks. Next in importance is the Pacific Ocean (35.1%), then the Caribbean Sea with 20.1%.

However, the same Master Plan of Irrigation and Drainage indicates that the total area of agricultural land with rainfall deficit indeed suitable for irrigation around 12.960 km^2 of land, equivalent to 49.84% of the total area identified. In 1992, the country's land area under irrigation was estimated 130,000 hectares (10% of the area suitable for irrigation), now considered covering 311.557 hectares, i.e. about 24% of the total area suitable for irrigation (according to the 2003 agricultural census).

Most of the irrigated area is undertaken by private initiative and not as a product of government policies, except for small farmers. The sugar cane cultivation has reached a surface of 269.400 hectares planted in 2004-2005, estimated that 80% of it is irrigated during the dry season. The higher rate of irrigation applied in the country is by spraying (54.2%), then 30.2% by flood, drip 6.1% and 9.6% for other systems. The major source of water used for irrigation is rivers (57.6%), 16.7% use lakes, ponds or pools, 0.3% a river or lake, pond or pool. The 74.6% of irrigation using surface water and groundwater 25.4%, in the absence of changes in management, the proportion of groundwater use will increase in future due to lack of surface sources. About 80% of the area under irrigation the country is on the Pacific, 16% in the Caribbean Sea and 4% in the Gulf of Mexico.

To estimate the water demand for irrigation in the country it was considered that the water is used almost exclusively in the dry period, or six months per year. Subsequently, there was an irrigated crop estimated by watershed, since the exact data not reported by the agriculture census, crop data were reduced to the most representative items for which estimated a specific irrigation frequency and a total contribution under water irrigation experience with these crops, following consultation with local experts with many years experience in the field. The crop area was estimated using the 2002-2003 census data as shown in Table 10 and the indexes used to calculate water demand are shown in Table 11. The area of irrigated cane occupies 54% of the total, African palm followed with 10% and bananas with 7%.

Based on the data shown in tables 10 and 11 and the distribution of surface irrigation and watershed system, it could be able to establish the water demand for irrigation in the country, as stated in Table 12. The demand for irrigation water in the entire country is estimated at 3668.18 million m^3.

The two more demanding systems flood water and spray (84.7%) and it is confirmed that the watershed of the Pacific Ocean has the largest demand for water (71.8%), being lower in the Caribbean (21.0%) and much less on the Gulf of Mexico (7.2%), with the greater water availability. It also indicates that although remains important flood irrigation (39.1%),

Table 9. Irrigable Area Based in Agrologic Classes (I to IV) And Rainfall Deficit (km^2)

Class Deficit	Drainage Basin Pacific Ocean	Drainage Basin Caribbean Sea	Drainage Basin Gulf of Mexico	Total Country
I	911	201	0	1,112
II	6,074	627	343	7,044
III	1,608	979	7,896	10,483
IV	624	3,478	3,482	7,584
TOTAL	9,217	5,285	11,721	26,223

Source: PLAMAR Lecture at symposium on irrigation, Chile 2001 (SEGEPLAN 2007).

this has been overcome by the sprinkler which demands the 45.6% of the water with such use can also be regarded as satisfactory that the country has systems drip irrigation as this increases the efficiency of water use.

Major producers keep records of how much water they consume; others only use it because of the low importance they give because it does not represent a cost. Those who consider its cost, because of pumping systems, are concerned and that is why preferring drip irrigation. Furthermore, information access hasn't be systematized yet.

Along with the irrigation water, it has been estimated water consumption for other agricultural purposes (coffee benefit, water for livestock, poultry, water exchange in the 1,500 hectare of shrimp ponds and others), as water demand is fairly lower than irrigation, although the unit consumption of these activities can be quite high and polluted.

6. Water and Industry

The primary industry consumes a significant water quantity. Unfortunately the state has no records of water consumption in the industries of Guatemala and these data are provided to the public by the industry themselves, so no one can estimate their efficiency. In this chapter an estimation of the volume of water demanded by the industry, including mining and tourism is done.

Industrial activity is concentrated in the metropolitan area of Guatemala (MAG), press the demand for the service provided through piped water supplies in the most cases of groundwater. To estimate the water consumption of this sector it has been followed the approach of the report of the Integrated Strategy for Water Resources in Costa Rica (2005), in which to make projections of water consumption for this sector is set a parameter of 80 m^3 per each $ 1,000 of added value. For Guatemala the figure of 80 m^3 was adjusted with an increase of 25%. The Guatemalan industry in 2004 produced the equivalent of USD 3565.9 million in added value at current prices. The structure of industrial production

Table 10. Guatemala: Estimation by Main Crops Irrigated area

Crops	Hectares	%
Banana tree	22,400	7.18
Sugarcane	168,490	54.00
Flowers and foliage	2,800	0.90
Lemon	3,500	1.12
Mango	3,500	1.12
Berries	350	0.11
African Palm	30,800	9.87
Papaya	980	0.31
pineapple	2,100	0.67
Banana	8,400	2.69
Grass	14,000	4.49
Other permanent	2,170	0.70
Melon	5,530	1.77
Tomato	2,800	0.90
Onion	1,320	0.42
Other vegetables and annual crops	42,900	13.75
TOTAL	312,040	100.00

Source: Estimated data. 2002-2003 Agricultural Census; (SEGEPLAN 2007).

Table 11. Data Used to Estimate Irrigation Water Demand (Thousands of Hectares)

Efficiency and equivalent crop	Total Surface	Sprinkling	Drip	Flood	Other	demand m³/ha	Irrigation/ year
Efficiency		0.7	0.9	0.5	0.6		
Equivalent cultivation							
Sugarcane	181.6	110.0	2.1	56.0	13.5	500	12
African Palm	43.0	20.7	2.0	17.3	3.0	340	27
Banana tree-Banana	30.8	14.0		14.0	2.8	500	27
Melon	9.8	3.0	0.4	5.0	1.4	525	25
Vegetables and other annual crops	46.4	21.3	14.6	1.9	8.6	280	24
Totales	**311.5**	**169.0**	**19.0**	**94.2**	**29.3**		

Note: For total data approaches the above tables do not always coincide; (SEGEPLAN 2007).
Source: Estimate based on agricultural census data 2002-2003 and criteria Specialist irrigation water demands generally accepted in Guatemala.

Table 12. Irrigation Water Demand (Million m³) by System and Drainage Basin

Drainage Basin	Total	%	Sprinkling	Drip	Flood	Other system
Pacific Ocean	2,743.62	71.8	1,450.31	44.50	1,052.41	196.41
Gulf of Mexico	123.03	7.2	59.63	0.62	39.89	22.89
Caribbean Sea	801.53	21.0	230.62	21.12	402.68	147.12
TOTAL	3,668.18	100.0	1,740.56	66.24	1,494.98	366.42
% of TOTAL	100.0		45.6	1.7	39.1	9.6

Source: Census data and indices of consultants specializing in the subject irrigation (SEGEPLAN 2007).

indicates that 66.8% comes from direct consumer-oriented processes, production for intermediate consumption accounts for 27.5%, while production for capital goods is 5.7%.

Under this configuration the water consumption in industry was estimated at 332.6 million m^3, which focuses on the MAG, in which it is located around 80% of industrial value added of the country. Additional to the MAG, there are small industrial in the departments and municipalities of Escuintla, Quetzaltenango and Teculután. As already mentioned, the industry has now solved the water supply through its direct and free access to wells and springs. However, over-exploitation of aquifers and some high cost and represents a substantial investment (power and deeper wells), and an estimated medium-term are not sustainable because it is felt beat down the yield of groundwater. Also, the construction industry is an activity that cannot develop without water. Estimates of the Regional School of Sanitary Engineering (ERIS) of the University of San Carlos (USAC), suggest that to build a 60 m^2 house is required about 10 m^3 of water.[3] Based on this indicator has been estimated, very roughly, the water requirement in this branch of economic activity.

The mining is gathering again in Guatemala with the opening of the Marlin gold mine in San Marcos, the possible return of nickel mining operations in Izabal and the granting of other reconnaissance and exploration licenses from the Ministry of Energy and Mines.[4] The mining industry has a dual effect on water availability, on one hand refers to water that is removed along with other minerals and the water used in processing minerals. Depending on the hydrogeology of the area, the volume of water extracted can be very important. The regional impact may not be important, but the local impact can be significant.

In the case of the Marlin Project, which extracts gold and silver in the highlands of San Marcos, the environmental impact study indicates it will take to process 1.5 million m^3 of water per year, of which 1.2 million will come from reservoirs lines and 0.3 million from groundwater.

The total requirements will be 4,110 m^3 per day, of which 822 m^3 would come from the well and the recycling of tailings pit 3,288 m^3. The company has entered into operations and hopes to exploit 2.1 million ounces gold and 28.4 million ounces of silver, contained in 13.2 million tons of material.[5] In the national budget is appropriated an annual water consumption of 0.3 million m^3 for the mining project in San Marcos and up to two times for mining projects that are developed elsewhere in the country.

3 Elías, Carlos Alberto, et al. Determinación del agua no contabilizada y análisis tarifario del sistema de agua de Planes de Bárcenas, en revista Agua, Saneamiento & Ambiente, ERIS, Facultad de Ingeniería, USAC – 2005.

4 To exploit nickel requires 500 m^3 of water per ton of product, one would expect a production of 14,000 to 24,000 tons per year the plant into operation. Communication: Departamento de Control Minero, Dirección de Minería, Ministerio de Energía y Minas.

5 Assessment Report Marlin Project, gold and silver mining in San Miguel and Sipacapa, San Marcos. Comisión especial de la USAC, Guatemala, marzo de 2005.

Guatemala it's targeting the inbound tourism as an important element for economic development (one of the three axes of the Competitiveness Agenda 2005-2015), hoping to keep over one million tourist arrivals per year, two of the four most-visited sites are associated with water bodies (Atitlan and Rio Dulce) and the State has established river basin authorities, although partly by its low budget results are not visible. In 2004, the country had a total availability of beds per day of 27,038, which, according to a report of the Guatemalan Institute of Tourism, has an occupancy rate of 48.9%.

Based on these data and with an average consumption of 500 liters per day and bed occupancy rate of 50% was reached to estimate demand for this sector, which has added a similar amount for the use of restaurants in general so that this branch of economic activity demand 4.93 million m^3 of water per year. Based on the data from this sector has also estimated the water consumption of the other activities of commercial and service sector.

In conclusion, more information about the pollution produced by industries and agro-industries is needed.

7. Human Water Supply: Quantity, Quality and Access

The piped water supply has improved significantly in Guatemala, as evidenced by data from the last three censuses of population and housing. Water coverage increased from 52.3% in 1981 to 68.4% in 1994 to achieve in 2002 74.6% of households in the country (household water, stream to any homes or public). Remain significant differences in coverage between urban and rural areas. By 2002 urban coverage reached 89.4% of households recorded, and the rural population stood at 59.6% (Table 13).

In Guatemala urban households represent 50.2% of the total and up 46.1% of the population, while rural households constitute 49.8% of the total made up 53.9% of the population.

Despite the improvement in the coverage rate expressed in relative terms, in absolute terms there is still a significant number of Guatemalan households that get water through carry (shallow wells, rivers or lakes or other precarious forms). According to population census 2002 this means a total of 116,395 and 443,196 urban households to rural households exceeding a total of approximately three million people, which shows certain inequities between the two areas and within urban, between different social strata .

Like many countries, Guatemala has committed to meeting the Millennium Development Goals among which is that of halving the proportion of people who in 2000 had no access to a reliable source of water that had not the basic sanitation service.

Empirical evidence indicates that, even when the water service coverage has significantly improved, the quality of service is not necessarily good, of all existing services only 15% of provides previously treated water for domestic purposes and the provision therefore is not continuous and with proper pressure to supply.

Additionally, charges for the services will not even cover operating expenses and maintenance that has resulted in the deterioration of existing infrastructure, the subsidy for urban areas and expanding the service through alternative systems-trucks tanks, for example-also of dubious quality and cost significantly higher than those of a traditional system, to the detriment of the needs of rural and / or marginal areas of cities.

The demand for the entire population of the country according to the allocations provided in Table 14, is 834.8 million m^3 (only in Guatemala City, the Municipal Water Company, EMPAGUA, produces about 120 million m^3 of drinking water per year). Since the population is located mainly in the Pacific watershed, there is demand of 485.28 million m^3 (58.1%) in the Gulf of Mexico demand is 132.46 million m^3 (15.9%), while in the Caribbean Sea is 217.07 million m3 (26.0%).

As will be evident later with the other applications, the potable water sector is where most problems are present, and satisfying them is a great challenge due to the dispersion of the rural population and in many cases, technical difficulties to its delivery point.

Coverage data indicate that must be addressed as a priority in rural areas and the metropolitan area and improve the quality of existing services. The need to modernize the water and wastewater subsectors is clearly.

In relation to the overall management of water, drinking water and sanitation subsector is linked first as a user, i.e. as a rights holder to use water-water entering the distribution system, to best practices in water use; and control of wastewater systems, water exiting the system.

Table 13. Households by Type of Service Water and Urban and Rural Sectors, 2002

Type of water service	Total Country	%	Urban	%	Rural	%
Total:	2,200,608	100.0	1,104,994	100.0	1,095,614	100.0
Piped water supply. Household water	1,458,480	66.3	880,704	79.7	577,776	52.7
Stream to any homes	93,729	4.3	75,587	6.8	18,142	1.7
Stream public	88,808	4.0	32,308	2.9	56,500	5.2
Wells	337,241	15.3	56,375	5.1	280,866	25.6
Systems-trucks tanks	49,000	2.2	25,886	2.3	23,114	2.1
Rivers or lakes	106,360	4.8	8,848	0.8	97,512	8.9
Other	66,990	3.0	25,286	2.3	41,704	3.8

Source: Population and Housing Census 2002.

Self-administration of services is subject to other statutory and not for the water authority to resolve them. The responsibility is to ensure that their rights to supply and monitor compliance with the retention obligations of providers and operators.

8. Pollution

Water pollution in different basins of the country is due to point sources (domestic, industrial and agro-industrial sewage) and nonpoint (erosion of soil with chemicals during rainfall runoff events). Table 3 shows that existing uses generate 1,540 million m^3 of wastewater at national level, which when discharged into surface streams or bodies of water, automatically limit or hinder subsequent uses of the natural resource receiver. Only 5% of the wastewaters are treated and even for the dilution effect, that's why all waters that receive those discharges get automatically polluted. The volume of polluted water that is discharged into the basins is 40% of the municipalities, 40% of agricultural activities, 13% of the industries and the remaining 7% of agro-industries.

However, the pollution load (BOD, COD tons per year) do not keep the same proportions as shown in one studied case, where agribusiness located on two basins on the Pacific watershed contribute more than load generated by the population. Even though no information or systematic control are available, a study case conducted as part of the strategy for integrated management of water resources, indicates that pollution load by biochemical oxygen demand (BOD) and chemical oxygen demand (COD) generated by agro-industry and industry is greater than the generated by the communities expressed in population equivalents.[6] Currently, pollution limits downstream

Table 14. Criteria to estimate the current demand for domestic water in Guatemala.

Tipo de abastecimiento	urbano (litros/persona/día)	rural (litros/persona/día)	demanda anual [millones m^3]
Piped water supply. Household water	200	100	732.65
Stream to any homes	100	75	28.93
Stream public	100	75	20.55
Well	50	50	39.77
Systems-trucks tanks	25	25	2.73
Rivers or lakes	25	25	6.35
Other	25	25	3.82
Total			834.80

Source: Datos censales del año 2002 (SEGEPLAN 2007).

productive use and control is a decisive factor for the policies of poverty reduction, especially in reducing infant and maternal mortality rates and does not contribute to improve the country's competitiveness. With the Regulation of Downloads and Reuse of Wastewater and Sludge Disposal, adopted in May 2006, is expected to a gradual process of decontamination to be completed in 18 years.

The greatest challenge now is setting up surveillance and institutional coordination necessary to implement and monitor operational compliance with these provisions.

9. Water in Urban Areas

As noted in Chapter 7, 89.4% of the population of the country's urban areas has water supply coverage; the urban population represents 46.1% of the total. However, around 625,000 people still do not have access to it through household connection (116,395 households).

In relationship with service quality, the empirical evidence indicates that even when the water service coverage has significantly improved, its quality is not necessarily good because of all existing services, only 15% of previously treated water is used for domestic purposes and provision is not continuous or is characterized of having the adequate pressure (the largest proportion of this percentage is the urban area). On urban areas the proper coverage reaches 76.7% of households, while the rural level is only of 16.8%.

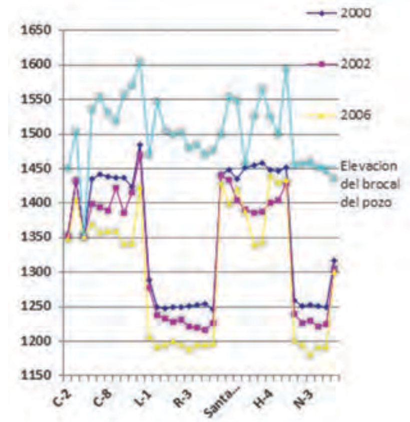
The percentages of loss in water service systems in urban areas reach 50%, while in rural areas the efficiency of water distribution pipeline is 90% (10% loss) and 80% in other forms of supply. In relationship with water prices, in urban and rural areas, charges for the services will not even cover operating expenses and maintenance that has resulted in the deterioration of existing infrastructure, the subsidy for urban areas and extending the service through alternate systems, -tank trucks, for example- also of dubious quality and cost significantly higher than those of a traditional system, to the detriment of the needs of rural and / or marginal areas cities.

The rates for water consumption are not very effective, except for the recovery in certain sectors by the municipal water company in the city of Guatemala (EMPAGUA), Agua Mariscal and other municipal water companies as Quetzaltenango and Santa Elena and San Benito. The average monthly fee for the service of drinking water nationwide is Q.4.5, when it's need it to be Q.30, Villa Nueva subsidizes monthly water in Q.1 million (1 US$ = Q. 7.5).

6 Population equivalents: The way to relate the pollution load generated by agribusiness and industry with the pollution load generated by the municipalities is by a factor called equivalent population. The way to do this is to divide the burden of pollution generated by agribusiness and industry, calculated by multiplying the discharge of water by the concentration of BOD and COD, between the pollution loads generated by a person, calculated by multiplying 200 liters per day per 250 milligrams per liter BOD (0.01825 tons / year).Population equivalents: The way to relate the pollution load generated by agribusiness and industry with the pollution load generated by the municipalities is by a factor called equivalent population. The way to do this is to divide the burden of pollution generated by agribusiness and industry, calculated by multiplying the discharge of water by the concentration of BOD and COD, between the pollution loads generated by a person, calculated by multiplying 200 liters per day per 250 milligrams per liter BOD (0.01825 tons / year).

The average price per cubic meter that EMPAGUA charges is Q.1.80, while its production cost is Q.3.50. Irrigation systems pay no fees for water use, so there's no motivation for having more efficient uses, although the shortage in some areas have changed to a lower loss method. The water supply for the MAG and other urban features includes two major challenges: the overexploitation of aquifers, with consequent increases in pumping costs, and the access to new sources that are outside their jurisdiction, which often leads to conflicts. In the first case the solution to the problem depends crucially on ordering the current exploitation of aquifers, through various management tools, whose application is the consensus between the parties. In the second case, it would be necessary to consider allocation and compensation mechanisms.

A case study conducted as part of the Strategy for Integrated Management of Water Resources was the over-exploitation of aquifers in the metropolitan area of Guatemala. FIG. 5 shows the changes between 2002 and 2006 in the groundwater level in wells I EMPAGUA Emergency Program, which show the tendency to deepen the water table.



SOURCE: EMPAGUA, 2006. REFERENCE PROYECTO EMERGENCIA I . WELLHEAD ELEVATION

FIG. 5. Declines in Groundwater Levels in the Metropolitan Area of Guatemala

10. Water and Sanitation

In sanitation matters improvements in coverage rates also have been noticed. Table 15 indicates that coverage has improved with proper disposal (toilet and toilet washable), 24.8% of households in 1981 to 46.9% in 2002, but is still too low to ensure an adequate quality of life for population, with almost six million people with no access to this basic service. In urban areas the proper coverage reaches 76.7% of households, while the rural level is only of 16.8%. Wastewater is treated at a few places (only 5% nationally), so that the wastewaters flows into rivers and surface water, polluting other water resources.

11. Water and Public Health

The Ministry of Health and Social Welfare (MSPAS) report of 2004 shows that were seen nationally 779,152 people with gastrointestinal problems, especially diarrhea also in the statistical report of the Guatemalan Social Security Institute (IGSS) for the same year, indicates that the total care consultations exceeded 650,000. In other words, it handled more than 1.400,000 events, which means that 12% of the total national population was affected. The average cost per visit, plus diagnostic tests and medicine per person reported, by the IGSS in that year for treatments associated with diarrheal disease, is Q. 287.68 per event. The public sector spends annually an amount greater than the Q. 400.000,000 (around $ 50 million U.S. dollars) due to gastrointestinal diseases transmitted by water.

Table 15. Households by Type of Sanitary Service, as Census Year

Type of Service	Census 1981	%	Census 1994	%	Census 2002	%
Total	1,151,872	100.0	1,591,823	100.0	2,200,608	100.0
Toilet	246,646	21.4	469,206	29.5	921,515	41.9
Needless washable	39,550	3.4	91,154	5.7	110,434	5.0
Latrine or cesspool	368,086	32.0	823,913	51.8	849,542	38.6
No one	497,590	43.2	207,550	13.0	319,117	14.5

Source: Population and Housing Census 2002, INE.

When performing a correlation with the indicators developed by WHO regarding the impact of investments in water supply and sanitation on health, is shown that at least a 10% reduction in diarrheal diseases could be achieved by investing $ 1 in them. We can conclude that for every $ 1 invested in these items would achieve a reduction of U.S. $ 5 from the budgets of MSPAS and IGSS and thus free up at least $ 5 million budgets.

Table 16 shows the departments ordered from highest to lowest proportion of morbidity reported of water-related gastrointestinal diseases.

The Second Progress Report Card for the Millennium Development Goals in Guatemala (2006) expresses literally "Getting families to have continuously drinking water and adequate sanitation is a fundamental goal. In fact, the family that enjoys these conditions will enjoy better health, better education ... and contributes in particular to improve the women situation... is conducive to better care for the environment ... "Invariably, the lack of these basic services is highly associated with high levels of poverty and extreme poverty". This Second Report ensures that if there was a 10% increase in the proportion of urban households with adequate water, there is the likelihood that child malnutrition would fall by 8.2% overall, and if the percentage of families who can't access to appropriate services be reduced from 13.68% to 3.68%, the reduction of maternal mortality from 153 to 116.33 per 100,000 live births (p. 219).

Table 16. Departments in Order of Highest Proportion of the Total Reported Cases of Gastrointestinal Illness in the Total Population

	Department	%
1.	Izabal	33
2.	San Marcos	21
3.	Alta Verapaz	21
4.	Retalhuleu	19
5.	Jutiapa	15
6.	Chiquimula	15
7.	Huehuetenango	15
8.	Quetzaltenango	14
9.	Sololá	12
10.	Zacapa	12
	National Level	12

Source: MSPAS 2004, cited by SEGEPLAN 2007

12. Water and Economy

Although, even if the share values of natural resources haven't been quantified yet in the national economy, including water, is easy to assume that more than the half of the nation's GDP comes from the use and exploitation of natural resources, as Guatemalan society is economically dependent on natural resource exploitation.

The Gross Domestic Product (GDP) is Q. 225,000 million and 71% of it depends on four major sectors of the economy, namely: a) agriculture, b) industry, c) trade, d) transport, storage and communications. The agricultural sector (23% of GDP) depends entirely on the water. Agricultural production is cyclical, is sown at the onset of the rains and harvested at the end of them. Perform off-season farming, means adding "artificial" water on the floor". It is estimated that the country watered a little over 310,000 hectares; this has required investment, whose financial value is taken into account, but is not always the direct contribution of water to increase yields of agricultural crops, as an important variable to look sustainably national water capital.

The importance of water in the national economy is also highlighted, considering that the country's main exports are related to the exploitation of its natural wealth, including water, since most relevant products are commodities and extraction, such as coffee, bananas, sugar, cardamom, gum and oil, they become virtual water and together represent an inflow of foreign exchange to the country close to 1,000 million dollars. Much of the industrial and agro-industrial sector are also demanding, and have to consume large quantities of water, this includes a variety of craft production. The construction industry is impossible without water. There is still a good margin of power generation based on hydropower, currently generates about 500 MW, equivalent to 35% of the total energy production, taking the country a potential of 4,000 MW and with the rising oil price makes it more feasible.

The great importance that the inbound tourism represents to the country, which seeks not only the cultural but also the natural environment, where water stands out as a central element of scenic beauty and necessary for the start value of this service, this sector also, becomes a serious applicant for water quantity and quality. Moreover, the government mining policy which favors these holdings represent a substantial increase in local and focus on the demand, consumption and disposal of water still worthless, with the addition that some of these holdings are located in the headwaters of watersheds where there is less availability of water naturally and from where it can contaminate surface and groundwater sources.

The importance of water resources in economic, becomes more relevant if it's considered that only the agricultural sector occupies about 50% of the EAP (refers to the total workforce and not working in irrigated areas), agro-industrial activity and crafts contributes 8% of the EAP, if its added other important economic sectors as tourism, hydroelectricity and mining, it can be stated that about 70% of the economically active of Guatemala depends directly on the use and exploitation of its resources water.

13. Water and Energy

The country has high potential for hydroelectric power (4,000 MW currently generates about 500 MW, equivalent to 35% of the total energy production). In the Pacific watershed rivers allow the handling of differential height, while on the Gulf of Mexico and Caribbean Sea are rivers with deep and long runs. Based on the records of the Chixoy hydroelectric, the single annual regulation reservoir has been carried out to estimate the water demand of the national hydroelectric complex, which while not directly consumptive, if it affects or restricts the uses downstream. As noted, currently, 35% of the country's energy is supplied by hydropower, but with the increase in oil prices, the State, through the National Electrification Institute, has revived interest in this type of energy, taking into holding several large projects, medium and small private investors to participate in its construction and operation.

Like mining, hydroelectric construction has been questioned by environmental NGOs and community groups. The questions are varied, from impacts on the environment to energy requirements and works of community interest. Nationally, only hydropower operation (Chixoy) has an annual regulation reservoir. This hydroelectric built at the beginning of the eighties led to resettlement of families, who even today are requiring redress and compensation. Post Chixoy, most hydroelectric projects have been built with daily control works and small dams. However, in one such project, for lack of foresight in the construction of a regulation reservoir downstream from the discharge of the powerhouse, triggering protests from irrigators. It should develop a process for the development of hydroelectric projects, through which communities participate, to minimize conflicts.

14. Floods and Droughts

Guatemala and other Central American countries are often affected by hydro-meteorological events capable of causing major disasters, especially manifested in excess and shortage of water that can alter life, infrastructure and property damage. Therefore, it is essential to know how these phenomena affect and to assess its significance in terms of its effect on development.

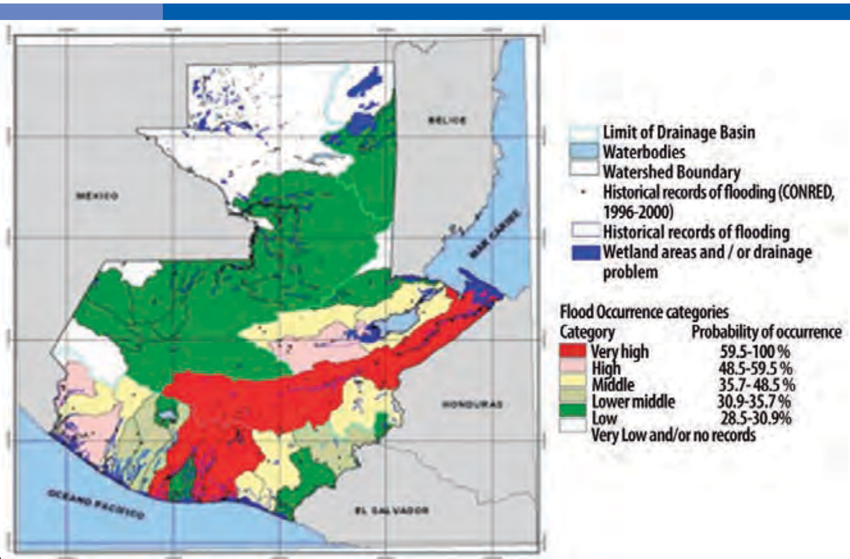
According to climate current trends, it is expected more intense and frequent occurrence of disasters. In this environment and because of the lack of implementation of land management policies, the population growing at a rapid pace settles an increasing number of high risk sites.

The dynamics of meteorological events that produce disasters is least studied and known throughout the country and therefore, management measures are not necessarily the most appropriate. In addition, construction of infrastructure has not been systematically designed to incorporate measures relating to how to deal in cases of extreme events and therefore is usually severely damaged when they occur. Likewise, there is no national system of protection that works to prevent flooding and/or protect persons and property and constructions are not designed considering the extreme event variable and sometimes even become a danger to humans and down waters works located original on a safe site. Hurricane Mitch struck the region in late October and early November 1998, killed 268 people in the country, 54,705 people were evacuated and about 105,000 were affected, the number of water systems damaged was 237, the total damage in the country were 948.79 million U.S. dollars. Hurricane Stan in October 2005, caused 669 people killed in the country, 12.445 houses damaged and destroyed 5,515, only in the department of San Marcos 331 damaged water supply systems, losses and damages valued at some 1,000 million dollars. FIG. 6 shows the occurrence of floods according to their probability of occurrence, divided into categories.

In relationship with to drought, the country has generated information on the most threatened areas, identified as extremely high to very low. FIG. 7 shows the areas of the country with an extremely high threat of drought to those with very low probability.

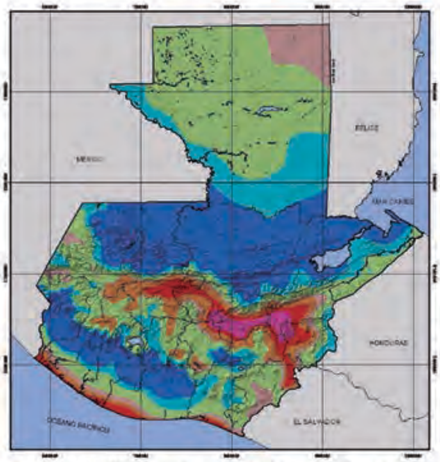
Although progress has been made in the local organization, still is necessary to work hard in developing planning and disaster preparedness. The topics on which emphasis should be placed are the knowledge of phenomena, development of early warning systems, local organization and incorporate elements of disaster to the infrastructure design.

The guarantee to life, physical integrity of persons and security of their property, also compete to make it effective the State which has organized the system of the National Coordination for Disaster Reduction to coordinate public and private actions risk management and has among its responsibilities set of particular and unique way for each and every one of the municipalities, the areas of risk. The policy of social development and population targeted six goals and thirty-one action to reduce disaster risks, including the strengthening of public administration and social organizations,



SOURCE: CONRED (2001).

FIG. 6. Flood Hazard Map



Degree of threat	Area (Km²)	(%)
Extremely high	116.46	1.53
Very High	3839.25	3.53
High	6523.75	5.99
Middle	7028.65	6.45
Lower middle	42160.47	38.72
Low	18223.57	16.74
Very Low	29443.87	27.04

Areas of the country and its degree of threat
Grado de amenaza. Degree of threat

SOURCE: CONRED (2001).

FIG. 7. Threat Due to Drought

a comprehensive plan land use planning, strengthen the comprehensive management of natural resources strengthen the response capacity of vulnerable people, better information about threats and promote a culture of disaster risk reduction.

Finally, it is important to highlight the state's institutional response on the issue of risk management, to the effects of extraordinary meteorological events. While government laws and policies facilitate the adoption of a national system of risk management, in practice this system has not been integrated. The National Coordinator for Disaster Reduction (CONRED), whose nature is eminently coordination with powers to declare areas of risk, is responsible for bringing together these efforts at all stages, prevention, care, management and reconstruction, in reality its scope has been reduced only to participate in the processes of emergency once disasters have occurred and does not have the power to implement its programs depend on other entities of government and society. Its ability to influence is very limited, scarce financial resources or circumstantial, as the post Stan allocation, and therefore has not been possible to develop the set of studies to identify local risks and threats and to recommend the respective measures prevention, management and disaster mitigation.

15. Legislation

Throughout the legal history of the country, the response of the State against legal and judicial issue of water has evolved in response to the specific needs of the country (sectoral laws and institutions), but now the realities of the country have changed so existing legislation is inadequate. It means, has covered certain aspects of the property, easements, use, development and protection of water, without incorporating the national

Table 21. Legislation Related to Water

Topic	Laws
Property and Easement	Constitución; Ley de expropiación, Ley de reservas territoriales del Estado, Código civil de 1963; y Código penal.
Use	Código civil de 1963.
Development	Constitución; Código civil de 1933 ; Código municipal; Código de salud; Ley de transformación agraria; Ley de minería; Ley de hidrocarburos; Ley de pesca; Ley general de energía; y Ley orgánica del INGUAT.
Protection	Constitución; Ley de protección y mejoramiento del medio ambiente; Ley forestal; y Ley de áreas protegidas.
Source: SEGEPLAN (2007)	

legal system a special law, as stipulated by the Constitution (1985)[7]. The legislative technique has been to include provisions in various legal texts. Among the most important regular hierarchy are the laws described in Table 21.

The ownership of the water passes under Guatemalan law mixed legal system, which recognizes public and private property, to the system of public ownership of all waters, as provided in Article 127 of the Constitution (1985).[7] This system has been adopted since mid-twentieth century by most Western countries, Britain, France, Germany, Spain, Italy, South Africa, Chile, Argentina, Costa Rica, Mexico, and almost all U.S. states of North America, among others. Historically, constitutions were incorporated into the public domain various categories of water.

Parallel to the debate over the ownership of water, there is the debate on rights acquired under civil law and land reform, and how they should regulate those from the Indian law, all of which the State has not responded, and the commitment contained in the Agreement on Resettlement of Uprooted Communities by Armed Conflict, to regularize water rights of its population.

Rights for fishing, energy, mining and hydrocarbons are considered by sectoral laws as accessories to a major right-mining, fishing, etc. The procedure for assignment is part of the main right and in any case not exists without the existence and coordination between different public entities.

Another important legal issue is the ineffectiveness of administrative servitudes of water, covered by civil law for domestic land use and irrigation, which involves informal management of State under the law, totally abandoned as mentioned above for a "market" of water rights and rights of way without complying with any regulation and not a few highly speculative and unsafe

7 While the 1985 Constitution incorporates "all" public domain waters, based on manifest constitutional history from the first constitution (1824) also guarantees private property and therefore it is necessary to regulate the property rights acquired under the previous civil law, which is incorporated to allow private equity categories of water while they were located on privately owned land.

practices. Without an effective system of servitudes will be impossible to carry water from areas with surplus to those with deficits and demand can be met at costs above the market if they can be exploited groundwater, otherwise the offer will be restricted.

Because water constitutes a natural element, mobile, spatial and temporal behavior, vulnerable to extreme weather events, the exercise of property rights or rights of use acquired and forecasting to meet future requirements, is related more to the integrated management of uses for the same water source, that the exercise in itself a property right.

Therefore, measures to regulate water rights involves parallel censuses, organize land registers and inventories of water. As a balance sheet, input and output of water and in ordinary times in extraordinary situations. Complex issue that requires decisions commensurate with the magnitude of expected benefits, if its desired to continue providing water to the economy and improve the quality of life and to reduce the causes of water conflicts.

The civil legislation of 1933, expresses the theme of stream gauging, water regulation and irrigation of the Agrarian Reform Law (1962) addresses the issue of the census of water for agricultural purposes, the previous Executive Agency Act (1945) in its reform of 1970, empowered the MAGA the inventory of water resources associated with agricultural activities. Neither institution today has any program or activity or inherited public administration management system at all. It means, there's not yet implemented a systematic program national, regional or local stream gauging and census sources for the use and problems and no government activity linking property rights and / or utilization of public waters and private use of water, with actual resource availability, and as a result the government does not have appropriate tools for water management. The above certainly jeopardizes investment transaction, inhibits use rights and causes conflicts between competing uses of water.

The law introduces a number of criminal offenses to protect the integrity of water assets, services and works, to protect public interest and the civilian regime likewise, processes to protect existing uses of new works or dangerous.

It is important to note that the state of Guatemala approved and ratified a set of conventions dealing with Sea Law, among which the rules governing government direction and navigable waters and environmental responsibilities of port facilities and other related environmental issues, including highlights, the Cartagena Convention on the Development of the Caribbean Sea, which, inter alia, requires states to have standards and measures to prevent pollution of water by ground source. Finally, it is important to note that the government has made a very special way to introduce regulations to manage mining, petroleum, forest and protected areas, considering these two key schemes to regulate the functions of the hydrological cycle and actually derived from these policies include programs to arrange payment for environmental services, but to date has not been legally able to order the administration of water to the detriment of public interest as the exercise of individual rights.

Water legislation main theme is to have a system capable of guaranteeing and balancing on one hand, access and use of water for social and productive and the other, provide measures for protecting the resource and thereby achieving safe and permanent supply the greatest number of demands.

The legal regime of waters is characterized by being composed by a set of rules in a number of laws, which at different hierarchical levels, addressing some issues of water management and a set of practices and customs which society Guatemala has been built. The legal system is based on values and principles of the nineteenth century and the institutional progress of centralization to decentralization and citizen participation, along with national policies in this area, while not being really a system of water management.

The country has no water law or an authority on the subject, contrary with what happens with the management of other natural resources such as forests, protected areas, mines and hydrocarbons, and implementation of existing legislation is related very poor. For example, it has a general scheme to assign rights and priority setting, which does not apply, in the register of existing use rights are not enrolled or 10% of them, which means a high degree of uncertainty their exercise, and rules laid down in laws of 1962 relating to the census of the land users and water, to date not been implemented.

The resource management is also expressed in a variety of administrative units and / or as part of specific programs and projects. Some powers are assigned to the Ministries of State and others, decentralized and autonomous entities, whose main activity is other (agriculture, mining, utilities, and natural resources). Other laws organized institutions for watershed management, with emphasis on conservation of natural resources, but none of these units is legally empowered to perform the basic functions of the integrated water management (management, administration, regulation, granting of rights, conservation).

All actors in water management have been identified, which do not have a structured dialogue space to communicate their interests, expectations and concerns because their objectives are of different nature. This fact is not unrelated to other parts of the world, makes water management is a highly complex and fragmented, where roles need to be clearly defined and differentiated state intervention properly defined.

More than 50 proposals to modernize the legal and institutional arrangements of water have been submitted during the past 20 years, but none has achieved significant institutional impacts. Therefore, to seize opportunities and address the challenges posed by water is necessary to move from the sectoral to the holistic management, a management level and mainly characterized by initial coordination mechanisms of planning and budget to enhance current efforts and then advance the implementation of own shares of integrated water management.

16. Conflicts

The current management of water resources reflects both institutional crisis within the government sector, dispersion of shares, vacant permanent temporary instantiation, programmatic and budgetary in coordination, as well as facts for or against government actions related to water uses (Hydroelectric Rio Hondo, Mina Marlin, Irrigation Ocosito, and conflicts over access to water sources for human supply throughout the country, among others).

The participation of different actors in water resources management is varied, both legal and functional perspective. Institutional have passed since when the state did everything, to a least intervention, and now is reassessing some of the functions that were weakened.

Across the country, mining disputes epicenter have often been a water source. Mining in Guatemala is an issue of social conflict that increasingly is uprising. According to Garcia, a former minister of Energy and Mines of Guatemala in 2005 were already being explored and exploited among nearly 400 mines; activity which has been operating since 1630.

Although the results of environmental studies ensure that mining operations cause minimal impact to the environment and socio-economic, reality is that some communities are opposed by pollution (use of chemicals such as cyanide and sulfuric acid are used to separate the minerals, whose presence in water is not possible to treat even in reservoirs with glue) and water consumption in areas of shortage (as the water evaporates should return due to high temperatures to which is after the process). Of the types of exploitation that exist, the open sky is that might create greater potential impacts to the environment and is most common in the country. The Catholic Church opposes these activities since seeks to defend the communities that are affected or at risk of becoming so.

In the vicinity of Lake Izabal mining operations were conducted in the past (70's). Currently this activity has picked up and Estoreña Association for Integral Development (AEPDI), fears for the 2009-2012 contract extraction of nickel and gold, which also allows the company to use some water from the lake. Since then, this situation has sparked conflicts and recently has been presented at the Social Forum of the Americas.

Due to the scarcity of water resources in some parts of the country, communities have agreed not to sell springs to other communities; internal measure not observed by some of the authorities, creating conflict over its management. The water supply of some of the major urban centers, encourages use conflicts with irrigation in the highland regions (where the aqueduct Xaya Pixcayá), and in coastal areas between large and small users of irrigation using a single source.

The case study of the Naranjo River basin in the Pacific side of the country, reported a relevant finding since has revealed that in the upper basin already entered a stage of water stress, as there is less available for 1,000 m^3 / person / year and has already led to conflicts resulting in access to resources between communities and individuals. Furthermore, the Naranjo River, presents pollution problems, since most of the population is at the top, and therefore water quality is impaired since birth, and then in the middle and low agro downloads are added. At the bottom, the floods that occur every year in the late rainy season, affecting the safety and property of persons located in the plains.

According to FAO, about 50% of the surface waters are taxed to Mexico, with whom there're water treats and adjoining boundary and water commission, but not for shared water use. Foreign ministries of both countries agreed to establish an international water agreement in 2009, following a border issue between San Marcos and Union Juarez in 2007.

17. Governance

Empirical evidence indicates opposing positions and strong of important interest groups in relation to who is the owner of the waters, of how rights are allocated for development and who and how externalities assumes positions that are not always consistent with constitutional standards and legislation.

Similarly, public institutions has been affected by the sectoral vision of unique applications, lack of coordination at central and municipal and social positions contrary to government decisions, as to the fate of water use, such the case of hydroelectricity with private participation.

Therefore, to move towards effective water governance, the proposed policy recommends build social pacts by which they distribute the benefits and costs of their exploitation, which could then be translated into public policy tools and new legal and institutional arrangements as well as social practices successful rescue of various characteristics.

Several of the current public policies consider the water sector approach and / or forest conservation and the environment. In the first case relating to certain uses and second, the water recharge Environmental Policy refers to a set of measures to protect water quality associated with the inventory of water and other actions for IWRM. Among others, the commitments of the peace agreements define the need to adjust the water use rights of uprooted populations. Forest Policy specifically includes actions to recharge aquifers and headwaters watershed protection and protected areas, payment for environmental services. Social Development Policy and Population refers to the risk management systems for water threats, and rural development considered important to introduce or improve water and sanitation services and proposes to set payment for environmental services cycle regulation hydrology.

While these policies concern secondary to some of the issues of integrated water management, do not express any strategic measure to ensure the participation of water in meeting its objectives and targets thematic, sectoral or regional mechanisms and lack of coordination between them. These policies will simply assume that water to meet the needs raised by them. Therefore, the draft policy aims to build bridges to bring the thematic and sectoral shares raised and give identity to the water in the process of national development through the institutionalization of coordination mechanisms for integrated water management within Policy Framework and Strategy.

18. Due to Global Change Scenarios

Global warming and increased ocean temperatures create the conditions necessary for the El Niño phenomenon is more frequent, and as a result, the country produces an alteration of the normal pattern of rainfall, accompanied by a decrease in the able to produce significant rain drought, especially after it disappeared.

As information available reads, the current trend is toward warming climate, which has direct effects on the behavior of water events that can cause disasters. Due to higher temperature, the thermal conditions of sea water, necessary for the development of tropical cyclones, is reached more often, so it is estimated that the number, size and intensity of tropical cyclones will increase, as indeed has experienced in recent years with high hurricane activity, with the 2005 season the most active of which information is available.

19. Water, Culture and Religion

The Mayan culture, over the centuries, has defended nature from a sacred point of view. The relationship it has with the living environment is harmonious and attributes life to everything, including water. In their worldview, the sphere of center (Ukux) is the heart of heaven, earth, concentrating and generates vital energy, and the water element, headed south (of the four cardinal points), represents the emotional body. One of the four elemental beings interacting in the ceremonies (deities and forces Kaculjas) is the energy or water undines (Cips Kaculjas). Within 20 nawals (glyphs that compose the Chol Q'ij sacred calendar, the basis of their spirituality and guide the development of life), is Imox, represented by the lizard, which is the principle source of water is the left side, the ability to break with the rigid structures and patterns. The lizard as a symbol in the Mayan universe that holds the world on his back and it determines that the rain arrives on time.

The conception of the world for the Mayan is the maintenance of the total balance, which implies a permanent concern for the environment, circumstances and nature of each entity at all. Water, considered divine spirit is respected as one of the formants of man, so also deserving of benevolence and identification. Where before birth, speaks with rivers and lakes, often called the song of the brook, the murmur of a stream, the silence of the wells, and the bravery of the torrential rain.

Victor Chaicoj (Mayan priest), note that each year the elderly organized to go to ask for rain in the hills, go at night and bring gifts, food and beverages. It is the best place to dialogue with the mountain spirit air, fire and water, to make possible the rain, in order to pray for the life of all beings depend on water.

Mayan religion is polytheistic: their gods are the elements (like water), atmospheric phenomena and celestial bodies; it's also dualistic, based on the principle that good and evil are equally divine, remaining in a constant struggle (as that affects the fate of humanity) and inseparable. The benevolent gods produce, for example, the rain (which is god Chac, the most popular descent, being by extension, the god of fertility and agriculture), while the malevolent, are blamed for hunger and misery caused by hurricanes and droughts (Ixchel, goddess of floods and other disasters).

In the Popol Vuh (Mayan sacred book), it is said that at the beginning of time there was only silence and stillness, from which emerged only sky and water (considered the origin of life). One day the creator gods, Hurricane and Gukumatz, did appear Earth and clothed it with rivers, forests and grasslands, which are filled with lots of animals. Then created unintelligent creatures without feelings, which ignored them, they, annoyed, the drowned under a deluge of water. Also, within their world, believe that before the world was, there were others, all destroyed by the flood.

According to their religion, after death the soul embarks on a journey to Xibalba (the underworld), where he must cross a river helped by a dog, the xoloitzcuintle, which can be understood as representations of the spectral journey.

The Mayan has a calendar for festivals and ceremonies. Among these practices Ch'a Chaak, headed by the H-men (a kind of shaman) invoke the chaques (helpers of the god of rain) when the rainy season is delayed.

Among the purifications to which they subjected the officials and participants of the ceremonies, there are the steam baths (also used by ballplayers, as it influenced their physical capacity, to cleanse diseases and muscle aches; widely used where water is scarce, as well as by pregnant women near the time of delivery), allowing them to reach the desirable state of mind and body to deal with acts of ritual.

Water is sacred in the Mayan religion, because the human body, like the animals and plants have a higher percentage of water area, if contaminated, a slow death occurs. Water is elemental used to make beverages in ceremonies such as balche fermented alcoholic beverage made from the bark of the tree balche water and honey, the Sakabe, corn and honey (other variants are pozole, pinole and gruel).

Historically, indigenous peoples have been subjected to deprivation of all kinds, including its cultural and natural heritage. They see the West as a threat, since they do the over-exploitation of resources and poor development being carried out. Persistently have a climate of corruption, impunity and lack of true democracy, both nationally and globally. The Maya believe that if given the international philanthropy, our food producers would have more life, stability and development, taking into account the importance of water.
Generally, communities benefit directly from water, but there is no central government policy that regulates its use. What exists is management of these resources, among others, the ancient Indian way, according to proprietary codes. The legislation, as well as most of the Ladino population, does not recognize their protection practices, water use and management of such legislation.

20. References

1. Aqua Vitae (2008): "Agua desde la cosmovisión maya". www.aquavitae.com
2. Centro de Acción para el Desarrollo y el Derecho (2006): "Exigimos

el cierre de la mina Marlin en San Marcos, Guatemala". Comunicados de organizaciones sobre minería.
3. Chaicoj, V. (2008): "El ser humano en la cosmovisión maya". Comunidad de comunidades nuestra señora de Guadalupe.
4. CONRED (2001): "Mapa de amenaza por inundación para la República de Guatemala". www.atlas.snet.gob.sv
5. Cultura solar (2007): "Cosmovisión maya". www.culturasolar.org
6. De la Garza, M. y Nájera C., M. (2002): Religión maya. Madrid, Editorial Trotta.
7. MAGA, UPIE, Laboratorio de SIG (2001): "Mapa de cuencas hidrográficas de la República de Guatemala".
8. Oilwatch Mesoamérica (2008): "La cosmovisión maya, como nueva estrategia para la conquista Q'eqchi'". www.deguate.com
9. Melgar, E. (2001): "El mar entre los mayas prehispánicos: cualidad de las aguas y su simbolismo". Derroteros de la Mar del Sur, año 9 N° 9. www.derroteros.perucultural.org.pe
10. Nabsas, N. (2005): "Conocer a los mayas". www.nocturnabsas.com.ar
11. Piñeyro, N. (2005): "Agua y semiótica". Revista POLIS 11.
12. Rivera D., M. (1991): La religión maya en un solo lugar. Universidad Complutense de Madrid. Revista Española de Antropología Americana, no. 21 53-76. Editorial Universidad Complutense, Madrid.
13. San Cristóbal Verapaz (2005): "Cultura e historia del municipio de San Cristóbal Verapaz y la gente pokomchi". www.sancrisav.net
14. Sandoval, M. A. (2001): Las aguas de Totonicapán. Estudio de Caso Manejo integrado de los recursos hídricos. CATAC.
15. SEGEPLAN (2007): "Diagnóstico y Estrategia para la gestión integrada de los recursos hídricos de Guatemala". Secretaría de Planificación y Programación de la Presidencia con apoyo del Banco Internacional de Desarrollo.
16. Sendero, P. (2008): "La religión maya".
17. Servicio de Información Municipal (2008): "Cultura del municipio Santo Tomás Chichicastenango, Quiché". www.inforpressca.com/municipal


Agua Azul Waterfall in Mexico

Water Resources in Mexico

Situation and Prospects

Editor
Ma. Luisa Torregrosa[1]

Authors
Ramón Domínguez Mora[2], Blanca Jiménez Cisneros[2], Edith Kauffer Michel[3], Polioptro Martínez Austria[4], José Luis Montesillo Cedillo[5], Jacinta Palerm Viqueira[6], Adolfo Román Calleros[7], Laura C. Ruelas Monjardín[8], Emma Zapata Martelo[9]

[1]Facultad Latinoamericana de Ciencias Sociales sede México
[2]Instituto de Ingeniería, UNAM
[3]Centro de Investigaciones y Estudios Superiores en Antropología Social, CIESAS-Sureste
[4]Instituto Mexicano de Tecnología del Agua
[5]Instituto de Estudios sobre la Universidad, UAEM
[6]Colegio de Postgraduados
[7]Instituto de Investigaciones Agrícolas de la Universidad Autónoma de Baja California
[8]El Colegio de Veracruz
[9]Colegio de Postgraduados, Programa de Desarrollo Rural

1. Introduction

The aim of this text is to concisely present the state of hydric resources in Mexico, as well as the main challenges, limitations and possibilities it faces for its efficient use.

2. General Information about the Country

Mexico is the world´s tenth most populated country with close to 107 million inhabitants; 75% of which are located in urban areas, while the rest is found in 184,748 localities with less than 2,500 inhabitants (Table 1). It has an annual growth rate of 1.4%. Its extension is 1,972.5 km^2, making it the 15th largest country in the world. As to its political organization, it is a Federal Republic, consisting of 2,438 municipalities, 31 states and one Federal District.

Table 1 Localities in Mexico and their population, Source: (INEGI, 2005)

Population	Localities	% Localities	% Population
‹ 2500	184,748	98.30%	23.5%
2500 – 15,000	2,640	1.40%	13.7%
15,000 – 100,000	427	0.23%	13.9%
100,000 – 1’000,000	112	0.05%	34.6%
› 1’000,000	11	0.01%	14.3%
Total	187,938		

Nota: According to INEGI, “urban” refers to towns with more than 2,500 inhabitants

3. Historical Background

The current management of hydric resources in Mexico results from the way they have been managed throughout the history of the country. Pre-Colombian cultures based their economies on irrigated agriculture, while in New Spain, waters were of public domain, meaning that although water was managed locally its use required a concession or grant.

In the XIXth century, as a result of the Lerdo Law, communities were dispossessed of their land and waters, resulting in the concentration of these resources in the hands of a small few. In 1915, the Agrarian Law, foundation of land reform, returned and provided land, water and mountains to communities once again.

Towards the end of the XIXth century and even during the beginning of the post-revolutionary period, the Mexican government began to centralize water management once it had studied the situation of the resource and after having built the relevant institutions. As the country developed, from 1950 to 1990 water use increased intensively in accordance with the Irrigation Law of 1926.

This brought about the construction of numerous hydrologic works of great importance to regulate rivers, as well as investment in the drilling of deep wells which in many cases led to overexploitation of rivers and aquifers as well as the desiccation of lakes, especially in the north and center of the nation where agriculture, industry and cities were flourishing.

Government reform in 1983 set the stage for decentralized management of water resources, returning the administration of water and sewerage services to municipalities; nevertheless the reform ignored communities that were already in charge of water management, provoking their confrontation with municipal heads. When the National Water Commission CONAGUA (Comisión Nacional del Agua) was created in 1989, decentralization policies included irrigation districts. In 1992 a new law for national waters was decreed and CONAGUA began to promote water markets and private investment in water services, including construction of infrastructure such as hydroelectric dams (Aboites et al., 2010).

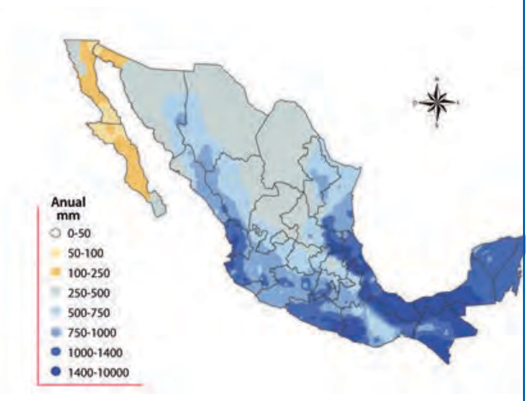
Unfortunately, this decentralizing process did not consider that nearly half of all water for irrigation was already administered by users. Finally, although amendments to the National Water Act in 2004 did not change many principals, it modified the way government operates.

4. Availability

4.1 Distribution of Rainwater

The average annual precipitation in Mexico is 775 mm (FIG. 1), equivalent to 47,980m^3/s (CONAGUA, 2008). Of these, 72% are evapotranspired, 26% corresponds to surface run-off, while only 2% is used. In addition, the country receives 1,586 m^3/s from the United States and Guatemala and sends close to 14 m^3/s to the United States in accordance with the 1944 International Water Treaty. Aquifer recharge reaches 2,471m^3/s nationally of which 889 m^3/s are extracted for use.

Agriculture uses 77% of water resources, 14% is for public supply, 5% is used to generate electricity and 4% for industrial purposes.



SOURCE: CONAGUA, 2008

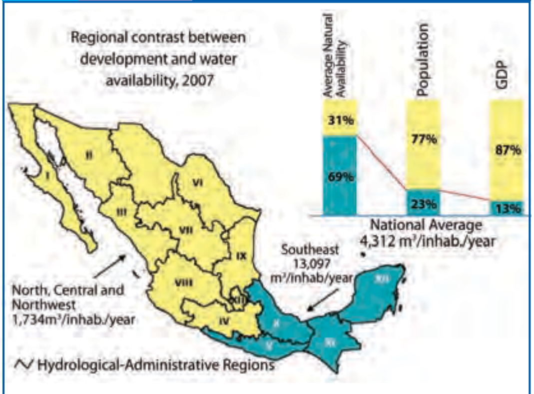
FIG. 1. Rainfall Distribution

Nevertheless, there are three factors that limit the use of water (Arreguín et al., 2010):

a) Temporal distribution, as it generally rains during the summer (from June to September), while the rest of the year is relatively dry.

b) Spatial distribution of precipitation, as the state of Tabasco, for example receives three times more rainfall than Baja California Sur (2,095 mm vs 160 mm).

c) Population distribution throughout the national territory, as although 77% of the population is concentrated in the Northern, Central and Northwestern areas of the country which produce 87% of the Gross National Product, these areas include only 31% of the country's natural water availability (FIG. 2).



SOURCE: CONAGUA, 2008

FIG. 2. Water Availability in Mexico

4.2 Groundwater

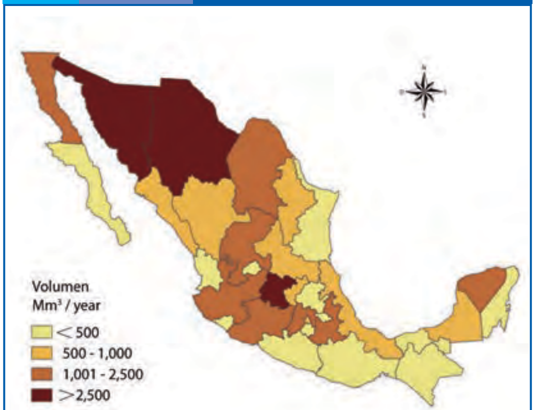
Groundwater is used to irrigate two million hectares of land (a third of the total irrigated land), covers 50% of industrial demand, provides 70% of the water used by cities and nearly all the water for rural populations. In spite of the importance of groundwater, over-exploited aquifers grew from 32 in 1975 to 104 in 2006. These more than one hundred aquifers represent less than 20% of the country's total, but provide nearly 80% of all extracted groundwater. The situation is critical in northern and central states, especially in the Río Lerma basin (Guanajuato and Querétaro); in the La Laguna region (Coahuila-Durango); the Baja California peninsula; Aguascalientes, Chihuahua, Sonora and Valle de México. It has been estimated that several of these aquifers have lost between 20 and 25% of their original reserves, while the rate of over-exploitation is 171m^3/s or nearly 50% of the water volume used for the nation´s public supply (Sandoval, 2010).

FIG. 3a shows intensity of groundwater use per state, while FIG. 3b shows the location of overexploited aquifers. It has been estimated that close to 40 million inhabitants depend on over-exploited aquifers, 35.5 million of which are found in urban localities and 4.7 million in rural ones. The following problems stand out with respect to the inadequate management of aquifers (Moreno et al., 2010):

- Lack of public information, deficient quantification of extraction, and, even when the extracted amount is known, as occurs in only one third of all wells, extraction is often greater than permitted.
- The lack of practical programs to control overexploitation.
- The fact that 20 overexploited aquifers are found within areas of free withdrawal or areas not included in a prohibition category. Many of these are found within the critical areas of Chihuahua, Coahuila, Nuevo León, Durango and San Luis Potosí (FIG. 4).

SOURCE: CONAGUA, 2008

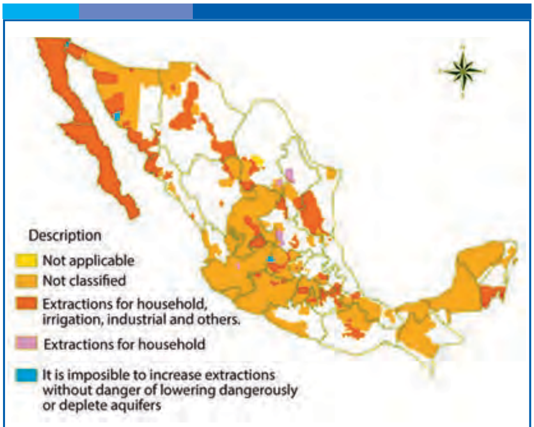
FIG. 3a Overexploited Aquifers



SOURCE: CONAGUA, 2008

FIG. 3b. Intensity of Groundwater Use per State

The decrease in groundwater levels has caused the disappearance of springs, native vegetation, wetlands, rivers, lakes and local ecosystems, apart from reducing flow and yield in the rivers, lakes and wells they supply. On the other hand, it has increased extraction cost, reduced quality, stimulated sea water intrusion in costal aquifers, and salinization of inner ones, plus differential settlement and cracking of the soil (Moreno et al. 2010). In addition, it affects surface water concessionaries, who go without compensation.



SOURCE: CONAGUA, 2008

FIG. 4. Prohibited Groundwater Areas

5. Uses

Consumptive use of water is classified as follows:

- Agricultural, which includes livestock and aquaculture;
- Public supply, for public and domestic urban use;
- Self-supplied industry in addition to agro-industrial uses, services and commerce;
- Thermoelectricity for non-hydroelectric generating plants.

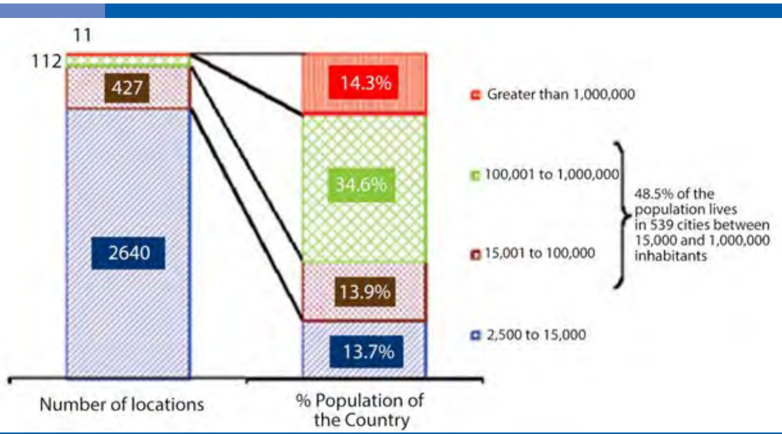
5.1 Urban Use

5.1.1 General Situation

In Mexico there are 3,190 urban localities, i.e. those with more than 2,500 inhabitants, containing 76.5% of the entire population of the country, FIG. 5. It is relevant to highlight the 11 cities with a population over 1 million, which are home to more than one of every seven Mexicans (Sandoval, 2010). In general these cities have a greater potential to obtain financial resources, either because they have stable taxing systems –such as the Monterrey metropolitan area or the cities of Tijuana, Queretaro or Leon-, or because their political importance allows them to have access to significant subsidies and exceptional conditions to finance the building of very large works of infrastructure, as is the case in Mexico City. Examples include the current works to increase supply and sanitize waters of the metropolitan areas of Mexico City and Guadalajara, both with in deficit taxation schemes (Sandoval, 2010). One third of the country's population lives in 112 cities with between one hundred thousand and one million inhabitants. The technical and financial performance of these smaller cities shows greater variation, although it can be said that it is deficient overall. Finally, the 3,067 towns with a population between 2,501 and 99,999 contain 27.6% of the total population and in most cases suffer numerous administrative and technical limitations (Sandoval, 2010).

In 2005, nationwide drinking water coverage was 89.2%, with urban coverage at 94.3% and rural coverage at 76.8% (CONAGUA 2005). Nevertheless, distribution typically is by programming supply at specific periods, and water quality, i.e. chlorination, is a problem.

On average, 76% of the volume invoiced is collected and the average fee per cubic meter is less than 30 US cents, that is lower than the average operation cost (Sandoval, 2010). On the other hand, less than 40% of the residual water generated receives treatment, and as a result more than 75% of the Biochemical Oxygen Demand (BOD) produced reaches water bodies, and thus affects their quality as a water source. Tap water supply relies increasingly on extraction of groundwater, and it already represents 70% of urban and 62% of industrial supply. The number of overexploited aquifers has tripled in the past 30 years and it is estimated that total extraction goes beyond 20% of their average yield. This circumstance clearly threatens sustainability in a country with an economy that relies ever more on urban-industrial activities (Sandoval, 2010).



SOURCE: INEGI, CONTEO 2005

FIG. 5. Distribution of Urban Population in Mexico According to Locality Size

5.1.2 Institutional Framework

The following is the course of the institutional framework for water management throughout the XXth century (Sandoval, 2010).

- From the mid XIXth century to 1948, services were under municipal management and occasionally supported by private businesses by means of concessions.
- Between 1948 and 1983, the federal government, located in Mexico City, centralized service control.
- From 1983 to 1989, responsibility of water and sewerage services was again transferred to municipalities.
- From 1989 onward, the creation on the National Water Commission began a new stage known as modernization.

In 1989, CONAGUA determined that agencies operating water resources lacked sufficient technical and financial capacity to properly supply services (Pineda et al., 2010). To overcome this situation, the Programa Nacional de Agua Potable y Alcantarillado, proposed that these agencies should:

- Operate as decentralized companies.
- Include management boards to fix fees or tariffs; among other functions.
- Use financial resources collected exclusively to provide services.
- Be financially self-sufficient as well as improve technical and administrative capacities.
- Use citizen participation as a lever to improve services.

Consequently, most state governments enacted their own sanitation and sewerage laws, and towards the mid-1990's, these services were managed by municipalities in 22 states. However, in the remaining states (Baja California, Durango, Jalisco, Nuevo León, Querétaro, Quintana Roo, Tabasco, Veracruz and Yucatán), management continued to be a state responsibility as municipal capacity was not considered appropriate to provide the services (Pineda et al., 2002). The agencies operating water services in the country follow a wide variety of schemes. In some states, they are decentralized and administered by municipalities; in others, they are inter-municipal state agencies; still others are committees or commissions controlling operation and domestic services in all or most of the state (Sandoval, 2010). Most organizations have chosen to continue being public, and only in exceptional cases, have services been given under concession to private businesses (CONAGUA, 2003). Examples include Aguascalientes and Cancún, service contracts in Mexico City and Puebla, and the mixed venture in Saltillo (CONAGUA, 2003). It has not been possible to establish fee approval by administration councils as a result of court rulings that determine that charging for water services is typified in fiscal terms as a right, and thus must be approved by legislatures (Pineda, 2008). Unfortunately, agency managers are appointed every three years according to political criteria, therefore rotation of personnel is high and the lack of adequate technical knowhow is frequent.

CONAGUA has set up several programs to improve urban water services, such as Drinking Water, Sewerage and Sanitation in Urban Areas (APAZU - Agua Potable, Alcantarillado y Saneamiento en Zonas Urbanas), The Program for Return of Rights (PRODDER - Programa de Devolución de Derechos) and The Program for

Modernization of Water Operating Agencies (PROMAGUA - Programa de Modernización de Organismos Operadores de Agua). APAZU builds and broadens tap water, sewerage and sanitation services in places with over 2,500 inhabitants. From 2001 to 2005, 2,526 million pesos were invested in this program, giving 426 thousand people access to tap water and 348 thousand access to sewerage systems; in addition sanitation services were improved for 2.5 million inhabitants and sewerage services for 3.2 million (CONAGUA, 2009). On average, this represents an investment of 390 pesos per person. On the other hand, PRODDER intends to improve efficiency and infrastructure by returning fees for the use of national water to operating agencies. In 2006, 1,495.8 million pesos were returned; in 2007 1,685 million and in 2008 a total of 1,941 million pesos (CONAGUA, 2009). PROMAGUA intends to support agencies that operate water services in places with more than 50,000 people so they may improve services by promoting private capital participation. Projects subject to support include: (1) those for the improvement of integrated management by means of actions directed to increasing physical and commercial efficiency; (2) those to supply water; (3) those for sanitation; (4) macro-projects, such as aqueducts and sanitation projects of great importance. Private sector participation is planned to be by three modes: through partial or integrated services contracts, by setting up a mixed capital company, or by granting a term of entitlement. PROMAGUA can provide a non-redeemable maximum of 49% for macro-projects and 40% in the remaining three types of projects. (CONAGUA and SEMARNAT, 2009). The development of operative agencies has also been hindered by financial aspects in the past. In 1992, CONAGUA created the so-called "blending of resources" in order to finance water services; thus the federal government contributes part of the funds as a way to direct investment priorities and maintain a degree of control over technical issues. This has given rise to a mechanism of virtual control by persuasion for the design, building and programming of actions, as well as to a certain degree, their operating performance, as a result of linking financial support to the compliance of conditions and specifications as determined by the federal authority. It is worth mentioning that this tendency is also used by The Program for Return of Rights (PRODDER) as the Federal Government returns fees collected for the right to use national waters to operators under the condition that they invest an additional amount in a project portfolio approved by CONAGUA.

The progress achieved by these three programs is shown in Table 2.
As to the results of these programs, national tap water coverage grew from 89.6% in 2006 to 89.8% in 2007; sewerage coverage increased from 86% to 86.1% in the same time span, and finally water treatment increased form 36.1% to 38%. In numerical terms the increases are only slight, and it is unclear if there have been improvements in service efficiency and private sector participation (Pineda et al., 2010), nor the advantages and benefits of these. Table 3 shows information for tap water coverage for the 21 cities for which data are available.

Table 2. Investment per Program and Source of Resources (2006), in Millions of Pesos

Item/ Source	Federal	State	Municipal	Credit/ Private sector/ Other	Total
APAZU	2,208.3	2,016.1	1,002.3	498.9	5,725.6
PRODDER	1,495.8	0.0	1,495.8	0.0	2,991.6
PROMAGUA	178.7	0.0	25.5	417.5	621.7

Source: CONAGUA (2009).

The situation is different in small rural communities, such as in "ejidos" or agrarian communities, or simple villages, as these manage their own water resources. Centralization of concessions and water management by the seat of municipal governments has been a source of conflict in the entire country, more so when municipalities have favored new developments.

Communities have been capable of self-managing their water resources by forming committees by honorary participation. Compared to municipal and operating agency management, they operate with profit, pay for the use of electricity and keep fees low. In contrast, municipal and operating agency management keep large payrolls, operate in the red while subsidizing payment of electricity with other income and by charging higher fees.

5.2 Use in Agriculture

At the beginning of the XXth century, Federal Executive and Legislative powers chose to re-launch the nation based on a model of hydro-agricultural development (Palerm et al., 2010). With time, Mexico stopped being a predominantly agricultural country and began industrial development. The hydro-agricultural development model, valid until the 1980´s, produced 86 irrigation districts. So-called "great irrigation" includes 561,388 users who can irrigate a maximum of 3,265,589 ha. For this purpose they count on approximately 300 thousand structures, 50 thousand km of channels, 30 thousand km drainage, and 70 thousand km of roads (Palerm et al., 2010). In spite of the above, in reality, not all irrigation districts are for "great irrigation" as the surface of 36% of these is below 5 thousand ha and in 32% it is between 5 thousand and 20 thousand ha (Palerm et al., 2009).

At the same time, there are approximately 2,956,032 ha of irrigation considered under "minor irrigation" also known since 1972 as, "irrigation units" or "irrigation units for rural development (URDERAL -Unidades de Riego para el Desarrollo Rural)".

The government has provided little follow up on these irrigation areas and much of the existent information was lost when the institutions supervising minor irrigation, i.e "juntas de aguas" or "water committees" on behalf of Dirección General de

Table 3. Characteristics of Cities with more than 500,000 Inhabitants

City	Population with access to tap water	Endowment L/ pers./day	Physical efficiency	Net use liters/ pers./day	Commercial Efficiency	Year reported
Acapulco	593,078	366	38%	139	87%	2005
Aguascalientes	659,701	340	56%	191	91%	2005
Cancún	567,963	283	79%	224	66%	2005
Cd. de México	8,277,960	334	59%	197	78%	2006
Chihuahua	716,781	460	53%	244	89%	2006
Ciudad Juárez	1,310,302	413	59%	244	79%	2005
Culiacán	613,144	288	67%	194	88%	2007
Guadalajara*	3,408,488	231	68%	157	n. d.	2005
Hermosillo	688,112	400	47%	187	74%	2007
León	1,086,298	205	57%	117	70%	2005
Mérida	795,146	346	36%	125	92%	2007
Mexicali	718,516	325	83%	270	61%	2007
Monterrey*	3,459,121	275	70%	193	99%	2006
Morelia	587,823	452	40%	181	56%	2006
Puebla	1,733,393	183	68%	124	70%	2007
Querétaro	612,156	310	51%	158	100%	2007
Reynosa	536,587	294	64%	189	65%	2007
Saltillo	597,584	221	55%	221	n. d.	2004
San Luis Potosí	921,958	291	51%	150	88%	2007
Tijuana	1,486,800	191	81%	155	70%	2007
Torreón	557,203	307	51%	158	86%	2007
Maximum	8,277,960	460	83%	270	100%	
Minimum	536,587	183	36%	117	56%	
Average	1,425,148	310	59%	182	79%	
Median	716,781	307	57%	187	79%	

* Metropolitan area
Source: Pineda et al., 2010

Aprovechamientos Hidráulicos of the SARH, URDERALES for CADER of the SARH's DDR, water for ejidos and rural communities on behalf of the Ministry for Agrarian Reform, were discarded.

Thus at present, there is little official information available on the number of users, irrigated surface, cultivation patterns and the most basic statistics on agricultural production and water volumes used.
Nevertheless, it is known that in 2006, the last year with statistical data for "irrigation units", these were more productive and had greater water yield than irrigation districts (Table 4). As with "great irrigation", the name "minor irrigation" doesn´t imply that all of these areas are truly small, as there are systems reported to have a size of 10 thousand hectares (Palerm et. al., 2009).

Production in irrigation districts has increased from 32 million in 1990, to 35 million in 2008, without increasing the irrigation area or the use of water; unfortunately information in this regard is lacking for irrigation units. Parallel to this increase, gross volume of water for irrigation –i.e. water extracted for irrigation from the supply source, including the volume infiltrated and evaporated during its conduction and distribution, has remained relatively constant at 30,000 Mm^3. This improved efficiency is due to: (a) better conservation of hydro-agricultural works, (b) improved efficiency of water conduction and distribution networks, and (c) improved techniques for land irrigation (Palerm et al., 2010). In spite of these positive results, irrigation districts and units suffer the following problems:

- Insufficient institutional capacity.- During the XXth century, minor irrigation organizations went through abrupt changes caused by modifications in legislature; while most recent legislation promotes smaller organizations instead of recognizing those already in existance. An additional problem is that modules continue to be controlled excessively by CONAGUA within water districts.
- Over-granting of concessions for surface water and poor registration and control of water use in the Public Registry for Water Rights (REPDA -Registro Público de Derechos de Agua). This registry has intended to record all water anew, instead of giving continuity to the concessions granted previously; a difficult task as there are 6 million hectares for irrigation and other uses of water in the country.
- Overexploited aquifers.
- Disproportionate concentration of water within some irrigation districts.
- Lack of combined management of surface and groundwaters.

5.3 Industry

Official information regarding water and industry is confusing, imprecise, hardly systematic and is not published in an updated manner; industry as a unit also lacks its own information (Aboites et al., 2008). Consequently, the true situation in this sector is not well known.

5.3.1 Use and Efficiency

Approximately 20% of the water used in the country, equivalent to 130 m3/person/year, is used industrially. In 2007, industrial use

Table 4. Comparison Between Irrigation Districts and Units in 2006, SOURCE: Palerm et al., 2010

Concept	Irrigation Districts	Irrigation Units
Number	85	39,492
Users	427,985	N/A
Gravity dams	271,061	N/A
Gravity derived	116,385	N/A
Pumped currents	5,786	N/A
Pumped wells	34,753	N/A
Physical surface area [ha]	3'496,902.00	2'956,032.00
Sown area	2'783,468.32	3'314,242.74
Harvested area	2'757,488.26	3'202,646.44
Irrigated area [ha]	2'481,807.83	2'846,296.00
Gravity dams	1'739,105.56	1'368,682.00
Gravity derived	432,817.07	
Pumped currents	34,480.17	1'477,614.00
Pumped wells	275,405.03	
Extracted Volume [Mm³]	30,401.30	35,060.36
Gravity dams	19,614.96	N/A
Gravity derived	6,821.98	N/A
Pumped currents	383.34	N/A
Pumped wells	3,581.02	N/A
Volume granted by concession [Mm³]	27,762.87	27,183.24
Surface Water	25,836.26	11,431.70
Groundwater	1,926.61	15,751.54
Production [tons]	42'966,081.58	68'703,736.56
Production value [M$]	55,936.29	87,624.29
Yield [ton/ha]	15.58	21.51
Cost in rural areas [$/ton]	1,301.87	1,239.48
Water productivity [$/m³]	1.84	2.50
Water productivity [kg/m³]	1.41	1.96

N/A: Not available
Sources: CONAGUA, 2007, 2008, 2009

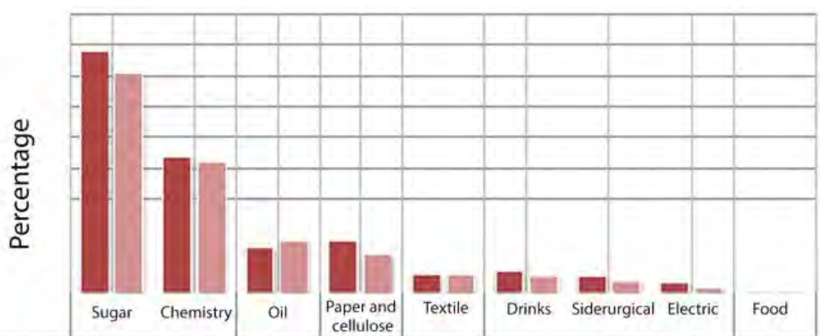
Table 5. Consumptive use of Water In industry, According to Extraction (m^3/s)

Use	Origen		Total Volume
	Surface water	Groundwater	
Self-supplied industry (excluding thermoelectric plants)	53.9	44.4	98.3
Thermoelectric plants	114.2	15.9	130.0
Total	168.1	60.3	228.3

Source. CONAGUA, 2007.

of water reached 7.2 billion m3, more than half of which is used to cool electric power stations. Table 5 shows the distribution of industrially used water. Some of the major consumers of water include oil refineries, iron and steel industry, paper mills, plus industries dedicated to timber, food processing, sugar production and manufacturing (CONAGUA, 2009a). Sugar production is the main water-consuming industrial activity.

Table 6 shows volumes granted by concession per state. The state of Veracruz consumes the most water with 1,150.6 Mm3. Likewise, Guerrero has the greatest volume granted by concession for use in thermoelectric plants at 3,122.1 Mm^3 due to the presence of the Petacalco coal-fired power plant (CONAGUA, 2009a). According to hydrologic region, Golfo Centro uses the most water, while Pacífico Sur has the smallest volume granted by concession. With respect to use by thermoelectric plants, the Balsas River area has the greatest volume granted by concession, while areas such as Noroeste, Pacífico Norte and Frontera Sur had no concessions granted for this purpose in 2007(CONAGUA, 2009a). Nearly 80% of the water consumed industrially is used in only six industrial activities: sugar production, chemical, oil, cellulose and paper, textile and beverages (FIG. 6). Of



	Sugar	Chemistry	Oil	Paper and cellulose	Textile	Drinks	Siderurgical	Electric	Food
Extraction	38.8	21.7	7.2	8.2	2.6	3.3	2.5	1.5	0.2
Consumption	35.2	21	8.2	6	2.7	2.4	1.7	0.7	0.2

SOURCE: CASTELAN (2000).

FIG. 6. Water Consumption by the Most Important Industries

Table 6. Volume granted by concession in 2007 for industrial use per state in millions of cubic meters

State		Self-supplying Industry	Thermoelectric plants
1	Aguascalientes	11.4	0.0
2	Baja California	79.9	195.1
3	Baja California Sur	8.2	3.9
4	Campeche	16.8	0.0
5	Coahuila de Zaragoza	73.5	74.9
6	Colima	24.4	3.8
7	Chiapas	29.4	0.0
8	Chihuahua	51.7	27.6
9	Distrito Federal	31.5	0.0
10	Durango	18.8	11.5
11	Guanajuato	56.0	20.5
12	Guerrero	12.5	3,122.1
13	Hidalgo	66.4	82.6
14	Jalisco	130.7	0.1
15	México	156.4	6.9
16	Michoacán de Ocampo	142.2	48.2
17	Morelos	59.0	0.0
18	Nayarit	55.7	0.0
19	Nuevo León	79.9	4.4
20	Oaxaca	39.1	0.0
21	Puebla	113.6	6.5
22	Querétaro de Arteaga	61.3	6.5
23	Quintana Roo	275.6	0.0
24	San Luis Potosí	29.2	41.0
25	Sinaloa	46.4	0.0
26	Sonora	78.0	0.0
27	Tabasco	58.9	0.0
28	Tamaulipas	103.7	54.0
29	Tlaxcala	19.4	0.0
30	Veracruz de Ignacio de la Llave	1,150.6	367.9
31	Yucatán	33.6	9.5
32	Zacatecas	19.5	0.0
	Total	**3,133.4**	**4,086.2**

the total industrial consumption, 50% is used in cooling, 35% in processes, 5% for use in boilers and 10% for services. It is calculated that these volumes supply close to 1,400 businesses, considered being the most important with respect to their water use and discharge (Castelan, 2000).

Based on the value published by the World Economic Forum, WEF, (2009) the consumption of electricity to treat municipal water (660 kWh per million liters) is close to 0.62 TWh. According to Scheinbaum et al., 2010, consumption of water in thermoelectric plants is highly diverse and may include the generation of electricity itself as it is based on water vapor, as well as the energy needed to treat municipal sewage water used by a variety of plants in the process. Unfortunately, the Federal Electricity Commission (CFE – Comisión Federal de Electricidad) provides no itemized information on how large these consumptive uses are. Table 7 presents a summary of the estimated electricity consumed for various uses of water.

Table 7. Estimate of Energy Consumed to Supply, Treat and Pump Sewage Water.

	Water Consumption	National Estimated
Uses	km^3	TWh
Irrigation	60.6	
Flood irrigation	n.a.	
Pumped irrigation (tariff 9)	n.a.	8.05
Public Self-supply	11.1	
Groundwater	6.9	
Surface water	4.2	
Tariff 6		1.51
Cutzamala		0.89
Tap water treatment	2.7	0.71
Treatment	2.5	1.65
Industrial treatment	0.94	0.62
TOTAL		13.43
% of national consumption		7.1%

According to the Water Capture, Treatment and Supply Census (Censos de Captación, Tratamiento y Suministro de Agua) performed by INEGI, 18% of the water supplied by the tap water networks was used by industry and services (CONAGUA, 2009).

5.3.2 Main Challenges

The following are some of the most important problems authorities face to implement the laws, rules and regulations needed to improve water use, reuse and treatment in industries (López et al. 2010).

- Authorities lack a detailed and precise diagnosis of the number of companies with well established systems for water and residual water management, and the situation these systems are in.
- Most industries, with the exception of the largest ones, lack the infrastructure and human resources for adequate water management.
- Deficient laws and regulations which do not promote sanctions and fines for polluting water, in addition to fines that are so low that it is often preferable to pay them repeatedly than to comply with the law.

- The lack of a strategic system to provide incentives for industries that promote and apply programs, actions and projects for cleaner production and the efficient use, reuse and recycling of water.
- The lack of social responsibility on behalf of many industries.
- Corruption and influence peddling while applying laws and regulations.

5.4 Ecological Use

It has been estimated that Mexico has nearly 14,523 m^3/s of blue water[1], or renewable freshwater available per year, and a total of 32,215 m^3/s of green water[2] per year corresponding to evapotranspiration (CONAGUA, 2008). Blue water availability is comprised by approximately 83% surface water and 17% groundwater. Considering that green water includes not only the water released through evapotranspiration but also the blue water that eventually turns into green water, the total water volume entering the Mexican territory, which is 1,920,725 m^3/s (3.93%), becomes green water by consumptive use. If the volume of water included in other consumptive uses is ignored, (1.19%), data suggest an environmental water flow, or water volume needed to feed rivers and lakes, of about 12,018 m^3/a (24.65%). These percentages are still higher than those of countries like India and Kenya, which respectively have values of 11% and 1.7% (Ruelas et al., 2010).

Table 8 and FIG. 7 show the environmental flow by hydrologic region. This flow fluctuates

1 Blue water. Water from rivers and aquifers.
2 Green water. Water used to produce green biomass, entering through the roots of plants and released into the atmosphere by foliage (Lundqvist and Steen, 1999).

Table 8. Water distribution in Mexico, according to the Falkenmark model

	Hydrologic administrative Region	Blue water (Mm^3)	Green water (Mm^3)	Gr-Bl water (Mm^3)	Environmental flow (Mm^3)
I	Baja California Península	4,616	18,034.64	2,889	1,113
II	North West	8,204	76,085.09	6,517	631
III	North Pacific	25,627	79,972.22	9,674	15,251
IV	Balsas	21,651	84,651.32	6,324	10,874
V	South Pacific	32,794	53,649.91	991	31,450
VI	Río Bravo	12,024	139,374.3	7,690	2,834
VII	North Central Basins	7,780	71,616.8	3,368	3,946
VIII	Lerma Santiago Pacific	34,037	254,422.1	11,444	20,165
IX	Northen Gulf	25,500	82,063.78	3,631	20,817
X	Center Gulf	95,455	61,103.87	2,873	90,588
XI	Southern Border	157,754	26,415.36	1,588	155,625
XII	Yucatán Península	29,645	125,639.47	1,343	27,512
XIII	Waters of Valle de México	3,008	6,379.44	2,240	-1,659

Source: Ruelas et al., 2010

SOURCE: Ruelas et al., 2010

FIG. 7. Distribution of Blue, Green and Environmental Water Flow by Hydrologic-Administrative Region

from 155,625 Mm3/year (4,935 m^3/s) in the Frontera Sur region to negative 1,659 Mm^3/year (negative 59 m^3/s) in the Valle de Mexico region.

Articles 14 bis and 15 of the National Water Law of 2004, establish that the national water policy should be sustained on integrated management of water resources per watershed, as well as the acknowledgment of the interaction between hydric resources and air, soil, flora, fauna, other natural resources, biodiversity and ecosystems, all of which are vital for water renewal. Policies for social and economic development must recognize the finite nature of water resources, the importance of their ecological, economic and social uses, as well as the interconnection with resources found in the watershed. In practice however, these objectives deserve low priority within budgeting allocation.

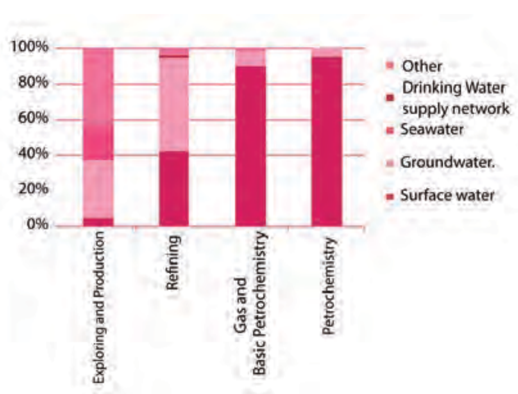
The 2008 CONAGUA budget assigned 65% for tap water, sewage and water treatment, whilst 20% was assigned for irrigation and 15% for administration and preservation programs (CONAGUA, 2008). In 2009, while budget distribution showed a similar pattern (53%, 23% and 21%, respectively), the investment in tap water, sewage and water treatment decreased in favor of administration and preservation programs.

Although Watershed Councils area a CONAGUA strategy to promote decentralization and participation of water users, ecological use as represented by the voice of members and that of society is practically non-existent.

6 Water and Energy

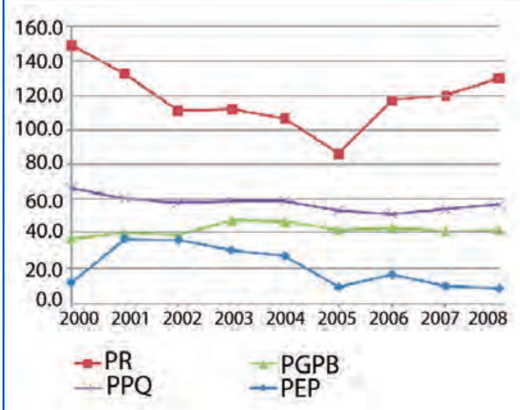
6.1 Use

Energy and water are closely related resources and are essential for human well-being. On the one hand, water is necessary to produce, transform and consume energy, and on the other, energy is required to pump, sanitize and treat water. In 2007, 5% of the water consumed in Mexico was used to generate electricity in thermoelectric plants, while in contrast, in the United States in the year 2000, 39% of water was used for



SOURCE: SHEINBAUM ET AL., 2010

FIG. 8 Water Consumption According to Source and Oil Industry Branch.



SOURCE: PEMEX (2001-2009)

FIG. 9 Tendencies in Water Use by Pemex According to Activity (Mm^3)

this purpose, nearly the same amount as in agriculture (Sheinbaum et al., 2010).

Public information concerning consumption of energy for the various activities related to water and sewage, is deficient, especially in big cities and municipalities with high and medium voltage rates. The reason for this is that water and energy policies and management are under the responsibility of various institutions, and with the exception of hydro-electricity, they hardly work in coordination, (Sheinbaum et al., 2010).

Water is used for a variety of activities in the energy sector, although it is mostly consumed in the processing and extraction of fuels; in addition, final consumption of energy implies minimal water requirements (Sheinbaum et al., 2010).

The main water sources for extraction and processing of energy are the rivers Coatzacoalcos, Huazuntlán, Ramos and Tamesí, as well as the Salamanca, Cadereyta and Tula aquifers, among others. In 2008, the total water resources used by Pemex reached 7,540 m^3/s, of which 3% corresponds to Pemex Exploring and Production (PEP - Pemex Exploración y Producción), followed by Pemex Gas and Basic Petrochemistry (PGPB - Pemex Gas y Petroquímica Básica) representing 18%, Pemex Petrochemistry (PPQ - Pemex Petroquímica) with 24%, and Pemex Refining (PR - Pemex Refinación), 55%. Nearly 52% of the water consumed for refining comes from groundwater sources and 42% from surface water, while most of the water used for gas, basic and secondary petrochemistry comes from surface sources (FIG. 8, Sheinbaum et al., 2010). Although the overall use of water for the various activities in the oil industry has been declining, water used to refine oil showed an increase between 2005 and 2008 (FIG. 9). Nevertheless, the figure for these years, 120 m^3/m^3 product, remained below the value for 2000.

These savings are the consequence of water recycling, and it could be said that the increases result from less efficient use. On comparing use per product between 2001 and

Table 9. Use of Water According to Production Unit (Use Minus Discharge) in m³ Water per m³ Product in 2001 and 2008

	2001	2008	Difference
PEP	0.13	0.01	92
Refining	0.86	1.03	-20
Oil and basic petrochemistry	0.8	0.61	24
Petrochemistry	6.39	4.66	27

Prepared with data from: Sheinbaum, et al., 2010

2008, a decrease is clearly observed for PEP and PPQ, but not for PR, where water use has varied greatly in recent years (Table 9).

Coal-fired power plants use water for cooling, lubrication of equipment and fuel processing, while thermoelectric plants use it in generator turbines and cooling processes. Because thermoelectric plants use the most water, older plants were built close to surface water and use open-cycle cooling. More recent plants use closed-cycle cooling systems and discharge 5% water. Most of the 130 m³/s of water used by thermoelectric plants in 2007 (88%) came from surface water bodies. It is worth mentioning that 76% of the water under concession for this purpose is for the coal-fired plant of Petacalco located off the coast of the state of Guerrero, very close to the mouth of the river Balsas (CONAGUA, 2008).

Thus, the Petacalco plant alone consumed 3.1 km³ (98 m³/s) of water to generate 13.4 TWh, while the remaining plants generated 185.5 TWh consuming only 1 km³ of water (31 m³/s).

The installed capacity of the national electricity sector is calculated to increase by 17,942 MW for the year 2018, of which 2,078 MW are programmed to be used in coal-fired plants. This not only has serious implications with respect to water use, but also will have impact on the environment and the import of coal (CFE, 2009). In 2007, 122.8 km³ of water were

Table 10. Consumption of Water in CFE Thermoelectric Plants (l/s)

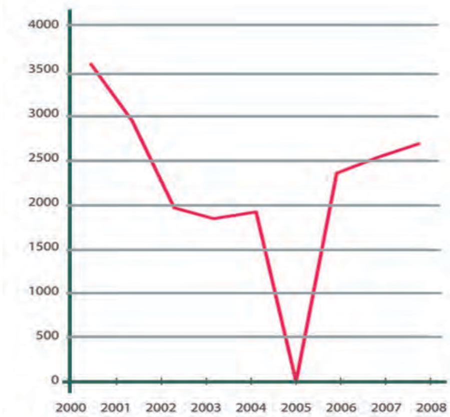
Source of water	Cooling and returned to cooling tower		Returned to cycle		Open cycle	
Conventional thermoelectric plant	**150 MW**	**350 MW**	**150 MW**	**350 MW**		
Sea water	321	749	20	47		
Well	144	336	6.5	15		
River	159	371	7	16		
Sewage	175	408	7	16		
Combined-cycle	**250 MW**	**450 MW**	**250 MW**	**450 MW**	**250 MW**	**450 MW**
Sea	214	321	4.5	6.5	13.5	20
Well	96	144			4	6.5
River	106	159	4.5	6.4	4.5	7
Sewage	117	176			4.5	7

Source: Scheinbaum, et al. 2010

used in the country for hydroelectric plants, which generate 12% of the nation's electricity.

6.2 Water Sources

Water consumption by the CFE in conventional and combined-cycle thermoelectric plants is shown in Table 10. It can be seen that CFE uses sea and sewage water in addition to surface and ground water. According to Pemex reports, treated water for reuse has been increasing, reaching 951 m^3/s in 2008, correspondingly residual water discharge has fallen, although an increase can be observed since 2006 (FIG. 10).



SOURCE: According to information by Sheinbaum et al., 2010

FIG. 10 Total Water Discharge by Pemex in m^3/s, Data lacking for 2005.

6.3 Contamination and Control

During oil extraction, water from underground formations is released along with oil and gas, this is called congenital water. Its quality varies according to the deposit, but in most cases it includes a variety of contaminants, noticeably, a high degree of salinity. This water is generally discarded at high cost, either by deep injection into land or by discharging it to the environment after treatment. Almost all congenital water in Mexico (88.9%) is re-injected (Most recent Sustainable Development Report to specify percentage reinjection). The Official Mexican Norm issued in 2003 determined the environmental specifications for the handling of congenital water associated to oil, and established the maximum permissible limits for various contaminants in congenital water discharge as well as the necessary characteristics that must be present in re-injection wells (SEMARNAT, 2003). As a result of the use of water treatment plants, discharge of contaminants has been falling. In 2000, total discharge was 5,541 tons, corresponding to 23% fats and oils, 61% total suspended solids, 14% total nitrogen and the rest to other organic compounds; while in 2008, total discharge was 2,486 tons, of which 15% correspond to fats and oils, 69% to suspended solids, 14% to total nitrogen and the rest to other organic compounds (Table 11). Since 2006, data on BOD and heavy metals have been published, and in 2008 they were reported at 1,306 and 28 tons respectively. Oil refining is the activity that generates the most contaminants. It is interesting to note that although organic compounds pose the greatest risks, even at very low concentrations, information about them is lacking. During 2008 more than 228,000 m^3 (7.2 m^3/s) of wastewaters were treated, of which 25,850 m^3 (0.8 m^3/s) were used to irrigate green areas and the rest for other purposes (CFE, 2008).

7. Quality of Water

7.1 Monitoring

Data on water quality are obtained through the National Monitoring Network, which in

Table 11. Water Contaminants According to Activity by Pemex (tons)

	2000	2001	2002	2003	2004	2005	2006	2007	2008
PEP									
Fats and Oils	84	53	55	38	41	81	101	60	41
Total Suspended Solids	297	260	228	224	229	320	306	329	222
Total Nitrogen	33.0	5.0	1.0	1.0	0.0	0.5	0.7	0.1	0.0
Other	71.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.0
Total Discharge	485	318	284	263	271	401	407	390	263
BOD						320	333	543	114
Heavy Metals							3.8	0.8	2.0
PR									
Fats and Oils	946	651	228	156	153	147	147	214	166
Total Suspended Solids	1,233	1,274	951	600	646	669	687	885	813
Total Nitrogen	513	689	450	386	283	233	227	286	263
Other	18	44	34	30	43	34	32	31	35
Total Discharge	2,710	2,658	1,663	1,171	1,125	1,083	1,091	1414	1277
BOD						586	565	749	526
Heavy Metals							10	14	12
PGPB									
Fats and Oils	50	53	55	50	44	133	49	96	80

2008 consisted of 389 permanent monitoring stations (207 of these located in bodies of surface water, 52 in coastal areas and 130 in aquifers) and 285 mobile stations (241 located in bodies of surface water, 19 in costal areas and 25 in aquifers) (CONAGUA, 2008). Mostof these stations are located in inhabited areas and some in industrial areas (FIG. 11), as a consequence information is lacking in many parts of the country such as the Baja California peninsula, Yucatán, Guerrero, Oaxaca and Chiapas (Jimenez et al., 2010).

7.2 Quality of Sources

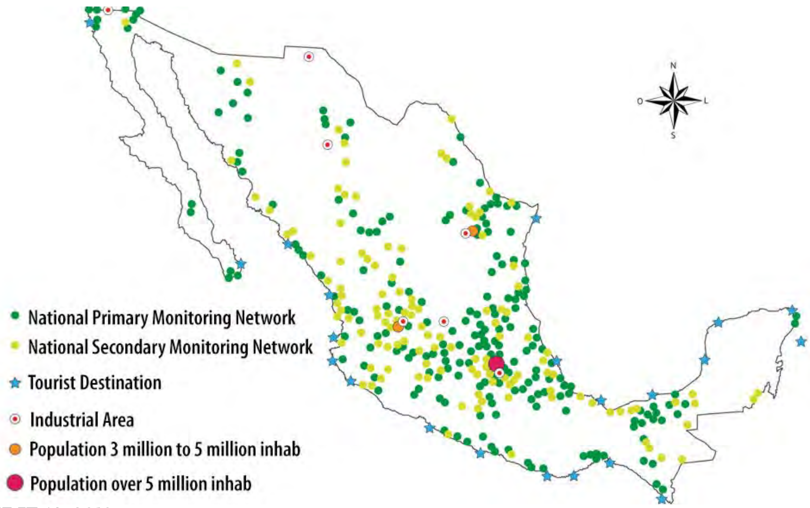
7.2.1 Surface Water

Surface water of excellent quality fell from 28% in 2003 to 24% in 2007. The opposite tendency was observed for water considered to be of good quality, showing an increase of close to 4 % in the same period, while water classified as strongly contaminated remained constant. Water of the lesser quality is found in the watersheds of Lerma Santiago, Balsas, Golfo Norte, Grijalva and Papaloapan, Bravo, Pacífico Norte and Golfo Centro. Information

Table 11 (cont.) Water Contaminants According to Activity by Pemex (tons)

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total Suspended Solids	322	220	233	198	200	741	175	214	229
Total Nitrogen	82	112	87	74	76	32	72	58	54
Other	5	7	6	5	5	13	6	8	4
Total Discharge	459	393	381	327	325	920	303	376	368
BOD							269	261	333
Heavy Metals								4	1
PPEQ									
Fats and Oils	140	156	85	59	104	133	66	76	81
Total Suspended Solids	1,418	691	622	819	359	741	464	414	459
Total Nitrogen	113	7	7	8	9	32	34	28	24
Other	16	3	2	5	4	13	21	15	14
Total Discharge	1,687	857	715	892	475	920	574	532	578
BOD						489	300	209	333
Heavy Metals							25	12	13

Source: Sheinbaum et al., 2010



SOURCE: JIMÉNEZ ET AL, 2010

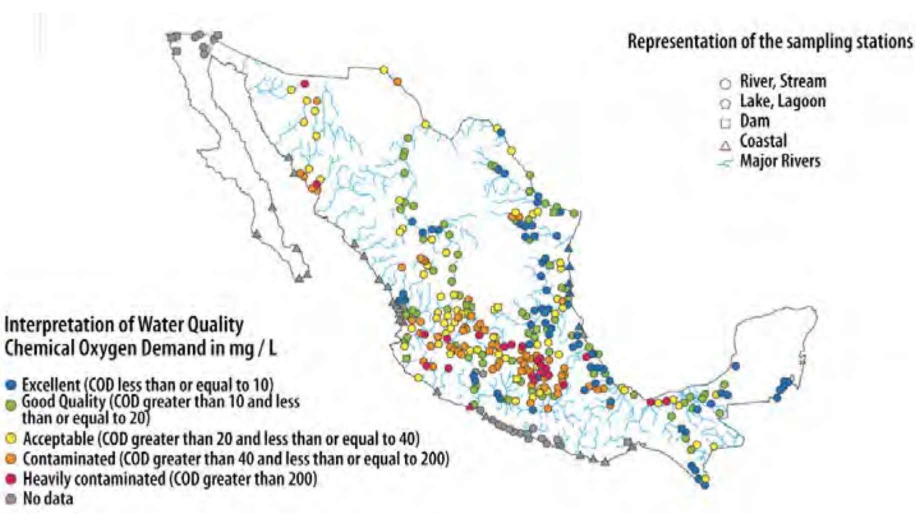
FIG. 11. National Monitoring Network Sampling Sites and Location of the Main Tourist Destinations, Population Centers and Industrial Areas.

for lakes and reservoirs is scarce, as it is only known that Chapala and Patzcuaro lakes have problems due to the presence algae and weeds. In addition, Chapala Lake presents problems caused by lead, cadmium and arsenic, as well as dioxin.

As to reservoirs, thirteen out of the fourteen included in the CONAGUA monitoring plan contain water of good to acceptable quality, while Endhó reservoir in the state of Hidalgo is catalogued as highly contaminated because it receives and stores a major portion of the untreated waters from Mexico City (Jiménez et al., 2010). According to content of organic matter, measured as Chemical Oxygen Demand or COD, the most contaminated areas are Valle de México, Lerma-Santiago-Pacífico, Balsas and Golfo Centro (FIG. 12).

7.2.2 Groundwater

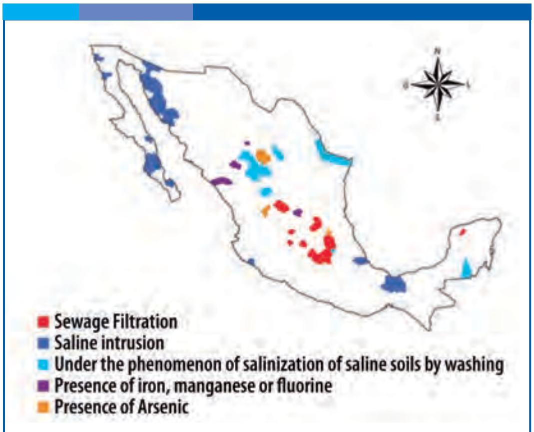
In general, the quality of water from various aquifers is deteriorating due to overexploitation and discharge of contaminants. Currently, there are 17 aquifers affected by this problem, in the states of Baja California, Veracruz, Sonora, Baja California Sur and Colima, plus 16 more in the north of the country (CONAGUA, 2008). Overexploitation can cause problems that in addition have serious effects on health, such as high concentrations of fluorine and arsenic of man-made or natural origin. Iron and manganesium, although not toxic, also affect potential use of water as they add color to it. CONAGUA (2005) reported concentrations of iron and manganesium in two northern aquifers, as well as arsenic in the Comarca Lagunera region. Since 1997 there is plenty of evidence of arsenic contamination in the aquifers of Zimapán in Hidalgo, Valle del Guadiana in Durango, and 17 municipalities of the Altos de Jalisco area. Likewise, there are high concentrations of fluorine (>1.5 mg/L) in the aquifers of San Luis Potosí, Durango,



SOURCE: CONAGUA, 2008

FIG. 12. Areas Most Contaminated by Organic Matter Quantified as COD.

Aguascalientes and Chihuahua. On the other hand, hexavalent chromium from both natural and anthropogenic sources has been found in the aquifer of the northern part of the state of Guanajuato, while overexploitation of aquifers in urban areas contributes to infiltration of residual water from sewage networks, although information on this is scarce. Residual water permeates eight aquifers in the central region of the country and one in Yucatán. This is reflected in levels of ammonia nitrogen and nitrates higher than the maximum allowed by the norms for drinking water in aquifers in Mérida, Tlaxcala and Valle de Tula, in Hidalgo; indeed there is evidence of fecal contamination in the water table of Tula and the southern part of Mexico City. FIG. 13 shows the geographical location of some of the aquifers mentioned above.



SOURCE: Adapted from CONAGUA, 2007

FIG. 13. Location of Aquifers Suffering from Quality Issues

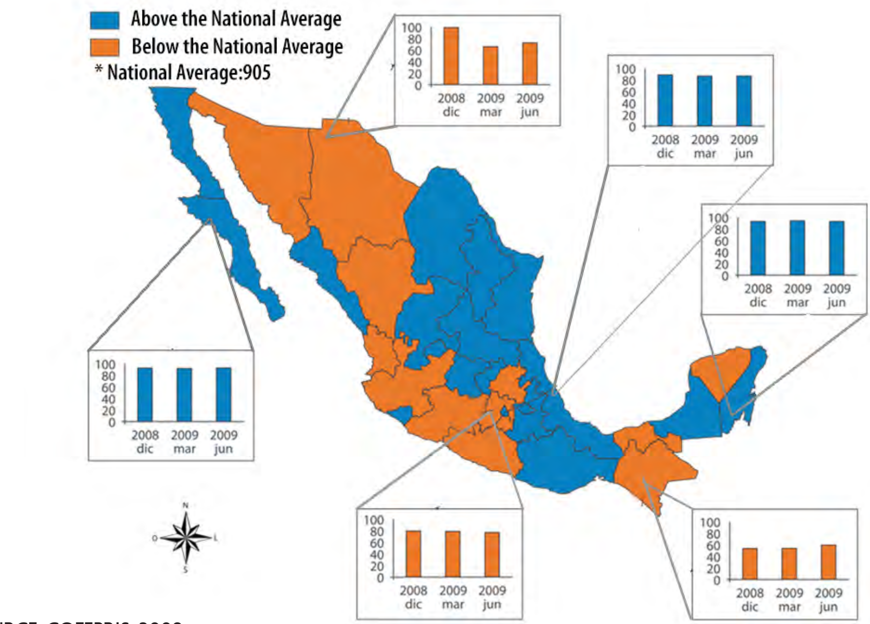
7.2.3 Drinking Water

According to data from COFEPRIS (Comisión Federal para la Protección contra Riesgos Sanitarios –Federal Commission for the Protection Against Sanitary Risks), in July of 2009, chlorination efficiency in the nation was on average 90.5%. While states such as Chiapas and Michoacán obtained values below the average, Baja California Sur, Quintana Roo and Coahuila show a chlorination efficiency of 100%. In addition, chlorination efficiency was observed to increase in the states of Durango, Tamaulipas and Chiapas by 17%, 8% and 6%, respectively, in contrast with Sonora and Chihuahua, where it fell 14% and 24%, respectively (FIG. 14).

Likewise, studies show that although water reaches homes with relatively acceptable quality, as it goes through home water tanks and cisterns, it deteriorates significantly; in other words, the lack of continued home maintenance is also a cause for decrease in quality (Jiménez et al., 2010). As to the quality of water in homes, very few studies have been published and the scarce data available only cover specific and occasional sampling to assess fecal coliform bacteria and residual chlorine, while excluding the 38 physico-chemical parameters established by the Mexican Norm. Agencies operating water plants in Mexico are under no obligation to sample water quality and make this information public.

7.2.4 Bottled Water

The consumption of bottled water is very important in the country, as Mexico is the world's second consumer of bottled water and the first consumer of bottled soft drinks (FIG. 15). It is worth mentioning that in spite of the high use of bottled water and the presence of the NOM-201-SSA1-2002 norm which refers to the sanitary specifications of bottled or packaged water, there is no public information on behalf of COFEPRIS with respect to its quality.

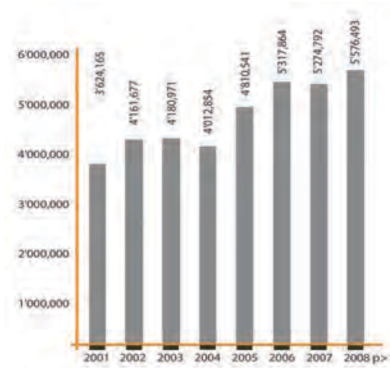


SOURCE: COFEPRIS, 2009

FIG. 14. Chlorination Efficiency per State for July, 2009 with Respect to the National Average and Some Historical Data

Buying bottled water is one of the most expensive measures to ensure drinking water quality. The high use of this type of water could be related to various aspects such as the world-wide growth of the sector, but there is also evidence of a relationship between the purchase of bottled water and deficient water services, especially with respect to programmed supply at specific periods, poor quality or lack of trust in quality. For this reason, the amount spent on bottled water is greater in poorer homes.

The results of a survey conducted in Iztapalapa, one of the regions in Mexico City with the lowest income and with serious issues regarding programmed supply and water quality, show that 91% of homes consume bottled water in contrast to 61% in the western region of the city containing higher earning households with better water services (Soto, 2007).



SOURCE: MAZARI ET AL,2010

FIG. 15. Sales Volume for Bottled Water (Thousands of Liters). (Source: Mazari et al., 2010)

8. Sources of Contamination

In Mexico, water contamination is mainly a consequence of rubbish being thrown into sewage systems, rivers and lakes, discharge from urban and industrial centers as well as contamination from agricultural areas, all of which are the main producers of diffuse contamination in the country.

From 1985 to 2007 the flow of municipal residual water increased 34% as a consequence of an increase in population from 58.2 million to 103.5 million in this period. Residual water volume from industrial sources tripled between 1992 and 1996, and from then on, has not shown important variations. Diffuse discharge of agricultural origin, reported occasionally, is nearly three times the volume discharged by municipalities (Jiménez et al., 2010).

FIG.16 shows the load of biodegradable organic contamination (BOD5) discharged into the environment, assuming that infrastructure for treatment works adequately when it is available. It can be observed that in 23 years, the contaminant load discharged by municipalities has decreased 16%, while that of industrial origin has doubled in the same period. As a result, the total discharge due to organic contamination from municipalities and industry has increased 45% from 1984 to 2007 in the nation.

8.1 Municipal Residual Water

It has been calculated that Mexico currently produces 431.7 m^3/s residual water from municipal and non-municipal sources; 243 m^3/s of these correspond to municipal sources, of which 207 m^3/s (85%) are collected.

Out of the collected residual waters, 83.8 m^3/s (40.5%) are treated while 123.2 are not.

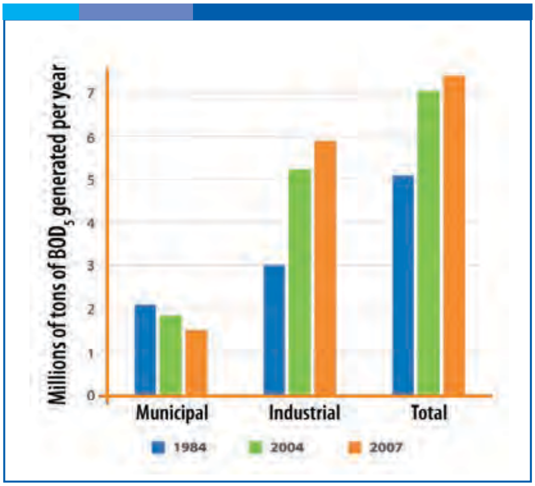


FIG. 16. Annual load of contaminants measured as BOD_5 discharged into the environment between 1984 and 2007 by municipalities and industry, after treatment (with information from Jiménez, 2005 and CONAGUA, 2008)

It is worth mentioning that in 1997, there were 1,712 treatment plants in the country, officially operating at 74% of their installed capacity.

8.2 Industrial Residual Water

In 2007, industry produced 188.7 m^3/s residual water, of which only 29.9 m^3/s (15.8%) received treatment in 2,021 plants operating nationwide (López et al., 2010). The most polluted watersheds receive industrial wastes and correspond to the rivers Grijalva and Coatzacoalcos, where the effluents of sugar and petrochemical industries are dumped. These watersheds are followed by the Papaloapan, receiving effluents not only from beer and chemical industries but also from distilleries and tanneries, and the Pánuco, contaminated by discharge from oil industries As occurs in most Latin American countries, vigilance and control of industrial contamination is scarce, especially with respect to "dry" industries, i.e. those that hardly use water or do not use it at all, and therefore do not register residual water discharge, although they do pour solid and liquid non-water wastes into sewers and surface and underground bodies of water. (Jiménez Cisneros, 2006).

8.3 Infrastructure for Control

8.3.1 Water Purification Plants

In 2007, there were 541 water purification plants in the country, although they were working at only 72% of their designed capacity (CONAGUA, 2008). These were processing close to one third of drinking water, while the rest of the water, due to its origin, was only disinfected.

8.3.2 Treatment Plants

8.3.2.1 Municipal

As a consequence of increased residual water discharge in the country due to population and industrial growth, CONAGUA has focused on promoting sanitation of specific municipal sources, although not all treated water complies with the corresponding regulations. Isolated reports state that in 1999, when the treated flow was 44 m^3/s, only 5% of it fulfilled regulations (Aboites, et. al. 2008), while in 2007, the 1,712 treatment plants in the country were operating at 74% of installed capacity, as previously stated.

8.3.2.2 Industrial

From 1999 to 2007, the flow of treated residual industrial water (of non-municipal origin) has been relatively constant between 30 and 40 m^3/s, although only 13 m^3/s of the total residual water produced by industries, i.e. 7%, fulfills regulations (Jiménez et al., 2010). By 2008, 31% of PTARI (Industrial wastewater treatment plants) treated their residual water primarily; 55% even reached secondary levels of treatment, while only 3% applied advanced processes (tertiary level). There is no specific information available for the remaining plants (11%) (López Zavala et al., 2010).

It has been considered necessary to complement infrastructure with other kinds of instruments to control contamination, in addition to increasing the number of treatment plants and the volume of water treated according to regulations. It is necessary, for example, to establish incentive and penalizing policies for those who produce, use or discharge toxic recalcitrant substances, i.e. those that cannot be removed in treatment plants or which can even cause them damage. It is also necessary to promote comprehensive watershed management by means of a program directed to the preservation and improvement of the quality of surface and groundwater under the current conditions and with prospect for the future (López et al., 2010).

8.3.2.3 Private Sector Participation

In the country, private participation in water treatment is much more common than in drinking water services. Treatment plants under this type of plan exist in Puerto Vallarta, Toluca, Chihuahua, Ciudad Juárez, Torreón and Ciudad Obregón. In addition, there are 26 cases of private participation in the building of treatment plants (CONAGUA, 2003), of which those in Mexico City stand out. The advantages of these concessions have not been reported, nevertheless there has not been an increase in the number of cases including private participation.

8.4 Use of Energy by Infrastructure for Control

Table 12 shows the use of energy by the infrastructure used for sewage and sanitation services. Use is underesetimated due to lack of information on the users paying industrial fees (Scheinbaum et al., 2010).

9. Reuse

Currently, several areas in the country depend on treated or untreated residual water for productive activities such as agriculture; therefore it is essential to officially recognize the reuse of water as an additional source of water. For example, Mexico is the second country worldwide, after China, in the use of crude residual water for irrigation of more than 180,000 hectares and treated residual water for irrigation of approximately 70,000 hectares (Jiménez, 2006).

According to water statistics in 2008, nearly 150 m^3/s residual municipal water were reused in the country. Transference to agriculture (87.5 m^3/s), stands out and to a lesser degree, industrial use (7,2 m^3/s). Reuse of industrial water from sugar refineries is basically directed toward growing sugar cane (42.8 m^3/s) and it represents half the volume of residual water used in agriculture (Ruelas et al., 2010).

Table 12 Estimate of Energy Consumed in the Supply, Treatment and Pumping of Sewage Water

	Use of Water	National Estimate
Use	km^3	TWh
Irrigation	60.6	
Irrigation by gravity	n.a.	
Irrigation by pumping (tariffs 9)	n.a.	8.05
Public self-supply	11.1	
Groundwater	6.9	
Surface water	4.2	
Tariff 6		1.51
Cutzamala		0.89
Purification	2.7	0.71
Treatment	2.5	1.65
Treatment in Industry	**0.94**	**0.62**
TOTAL		**13.43**
% National Use		**7.1%**

Source: Sheinbaum et al., 2010

10. Effects on Health

10.1 Information and Overall Situation

Although Mexico is a country with median income, the health risks it suffers are greater than those of similar countries, mostly due to the fact that water-borne diseases are still among the five main factors that affect health (Mazari et al., 2010). According to Mazari et al., (2010) a detailed analysis of the problem is difficult due to quality of the information, especially because:

- Gastrointestinal diseases of fecal-oral transmission are not only associated with the consumption of contaminated water but also of contaminated food, including foods eaten raw (for example, salads). Thus, if this information is used, it might be assumed that food contamination is due to contaminated water and not its unhealthy management.
- The categories considered by the Epidemiological Bulletin issued by the Ministry of Health (SS –Secretaría de Salud)

are variable, that is, the categories reported are not consistent, making follow up for a specific disease complicated and long term comparisons, impossible.

- It is not possible to know the situation with respect to viral gastrointestinal illnesses, as these cases are added onto those of ill-defined diseases (A04, A08-A09). This point gains relevance when it is noted that the number of cases included in this category is more than 4 million a year.
- As stated above, México is the second consumer of bottled water in the world and the first consumer of bottled soft-drinks. An important part of the population does not consume water from water distribution services, whether or not they have good supply services.

These facts cause confusion when it is intended to relate coverage of disinfected water supply and incidence of gastro-intestinal diseases.

10.2 Water-borne diseases

Table 13 shows water-related diseases in Mexico as classified by water authorities and health authorities. The difference between data from CONAGUA and the Ministry of Health in relation to these illnesses leads to recommend more extensive water vigilance by CONAGUA to include additional diseases present in the country, and especially to

Table 13 Classification of Water-Related Diseases

Agent Category	Organism/Infection	Type of Pathogen	Considered in México
Water-borne (fecal-oral)			
Diarrhea/Disentery	Escherichia coli , Cholera, Campylobacter, Salmonellosis, Shigellosis	Bacteria	CONAGUA, SS
	Rotavirus, Norovirus, Adenovirus, Hepatitis	Virus	SS
	Giardiasis, Amebiasis, Cryptosporidium	Protozoa	SS
	Ascaris, Trichuris, Taenia	Helminthic	SS
Intestinal fevers	Typhoid, Paratyphoid	Bacteria	CONAGUA, SS
	Poliomyelitis	Virus	CONAGUA
Water-contact	Skin and eye infections	Bacteria Protozoa, Virus	SS
Water-based	Schisostomiasis	Helminthic	SS
Propagated by Insect vectors related to water	Malaria/Paludism, Oncocercosis, classic and hemorrhagic dengue fever, trypanosomiasis	Protozoa, Helminthic Virus	SS

Source: Mazari et al., 2010

consider detection and quantification of the organisms related to them. The following are considered by the Ministry of Health as intestinal infectious diseases and by CONAGUA as those relating water quality to disease incidence: intestinal amebiasis, shigellosis, typhoid fever, giardiasis, intestinal infections caused by other organisms and those that are ill-defined, bacterial food poisoning, paratyphoid fever and other salmonellosis, as well as other intestinal infections caused by protozoans.

10.3 Comparison with Other Countries

The incidence of infectious intestinal diseases reported in Mexico is greater than that in countries with a similar GNP such as Argentina and Chile and could be related to better coverage of basic water services in these countries. In addition, it is also important to consider the differences between developed and developing countries.

The prevalence of Helicobacter pylori in young children for example, is greater than 50% in developing countries while it is usually less than 10% in developed ones. In Mexico, H. pylori infection has a seroprevalence of 20% in children below the age of one and 50% in 10 years old, while in 25 years old adults it is greater than 80% (Mazari et al., 2010).

10.4 Poverty and Health

It has been estimated that improvements in public infrastructure to provide homes with water has an impact of close to 30% on the reduction of diarrheic disease (SEMARNAT, 2008). A study by Guevara et al., (2010) found that the lack of water and sanitation services is indeed related to infant mortality. The strongest relation is found between infant mortality and the lack of piped-in water from public networks, followed by the relation between infant mortality and the lack of sewage and finally the relation between infant mortality and the lack of toilets in homes (although the relation is weak, it is nonetheless positive).

Likewise, people beyond poverty conditions have greater access to public services, thus an average of 2.5 infant deaths per 100,000 inhabitants is observed in those states below the national food poverty level and 1.7 per 100,000 inhabitants in states above it (Guevara et al., 2010).

11. Economic Development

11.1 Relationship with Water Availability

Although it is widely believed that economic and human development are related to water availability, this frequently is not so (Montesillo et al., 2010). Mexico has a GDP per capita of USD$14,560, ranking 55 among 176 countries, while its HDI (Human Development Index) ranks at 55. In contrast, it ranks 95 with respect to annual rainfall.

Montesillo et al., 2010 proved that, similar to what occurs in countries, natural water availability in individual states is not related to economic and human development (quantified by Pearson correlation coefficient). In fact, based on their analysis they point out the following:

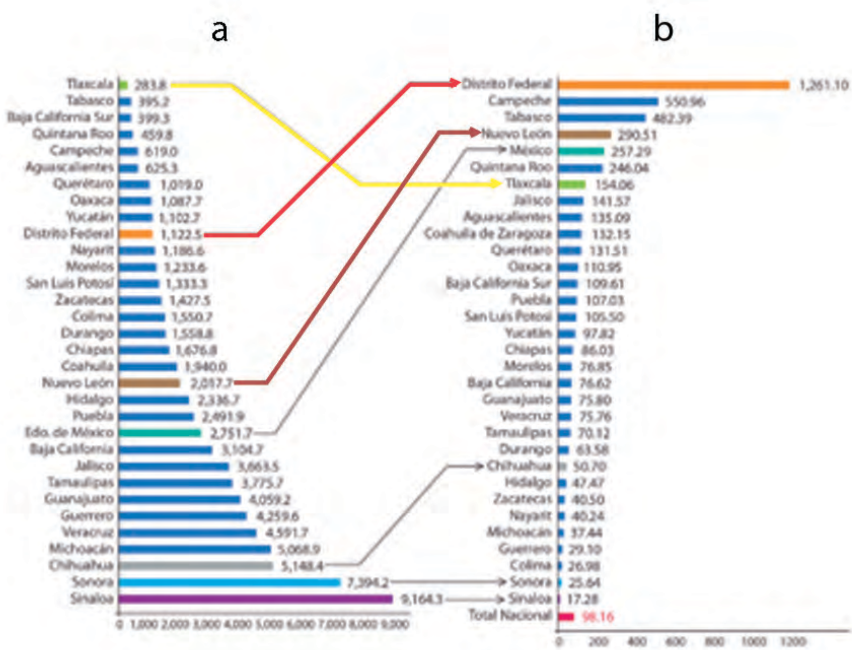
- The greatest concessions for water exploitation exist in states with the lowest natural water availability, which in turn are less densely populated and register the lowest water productivity, not only regarding aggregate information but also information from agricultural and industrial sectors;

- States with the lowest number of concessions have the highest water availability and exploit water most productively;
- States with the highest levels of natural water availability are the least developed and register the lowest rates of human development; and
- States with most concessions receive the greatest allocation for hydraulic works from the Federal Expenditure Budget (FEB).

Therefore, it can be concluded that the states with the highest investment in hydraulic matters have the highest development, although the order in which this has happened is not clear.

11.2 Water Productivity in Mexican States

FIG. 17 shows the relation between water concessions (a) and water productivity (b) per state. Productivity results from dividing the average total Gross Product per state in 2003-2007 in basic values and in pesos of 2003, by the total volume of water concessions per state, in pesos of 2003, per cubic meter of water. Thus, the cases of Tabasco, Campeche, Quintana Roo, on one hand, where rainfall is very high, and Sonora and Zacatecas, where rainfall is very low, confirm that natural water availability or its shortage has nothing to do with its productivity or the volume of concessions based, according to FIG. 17b. Furthermore, the figure shows clearly that the states where water is less productive are



Source: Developed from Montesillo et al., 2010

FIG. 17 Total Volume in Concession, 2007 (Mm^3) and (b) Water Productivity in Basic Values, in 2003 Pesos, per Cubic Meter of Water in Concession, 2007.

those that register the highest volumes of water concessions, such as Sinaloa, Sonora and Michoacán, among others. Although, in general terms and based on the aggregate information per state, water productivity is inversely proportionate to the volume of concessions, an in-depth analysis by economic sector is necessary, according to domestic accounting systems. However, information available about water concessions does not allow this job to be done (Montesillo et al., 2010).

Although detailed information is lacking, analysis can be performed for some sectors, such as sector 11, which involves agriculture, livestock, forest exploitation, fishing and hunting. From the information and data by Montesillo et al., (2010), it is possible to conclude that states with the highest concession of water, such as Colima, Sinaloa, Sonora, Hidalgo and Tamaulipas, have low economic efficiency related to water for agriculture. On the other hand, Federal District, Tabasco, Oaxaca, Jalisco, Quintana Roo, State of Mexico, the entities with the lowest concessions of water for agricultural use, have a higher productivity in this regard.

11.3 Rainfall, Volume Granted in Concession and Human Development

The correlation coefficient between HDI and rainfall has a negative value of - 0.141, and can be interpreted to mean that the higher the natural availability of water, the lower the value of HDI (Montesillo et al., 2010). Likewise, the relation between HDI and the total volume of concessions per state (coefficient of -0.092) is also negative, although because the value is low, it could imply that there is no relationship. Therefore, we can conclude that natural water availability, quantified by rainfall and total volume of concessions are not factors for economic or human development. According to data from the Federal Expenditure Budget (FEB), the states with lower volumes of water granted by concession and higher natural water availability receive less revenues to control, manage, treat and distribute water. This explains the higher number of inhabitants without domestic piped-water service, the higher mortality due to hydric factors and, consequently, the lower HDI. Thus, the volume of water in concession and the FED contribute to emphasize HDI inequality in states. Furthermore, in correlating the data of Table 14 we obtain that the higher the rainfall, the higher each of the following factors: percentage illiteracy, percentage population with incomplete elementary education, percentage population in homes without electricity, percentage population without sewers and sanitary utilities, and percentage dwellers in homes without piped water; in summary, the higher natural availability of water, the higher poverty level and, therefore, the lower HDI. The concession volume has no relation to the indexes because the correlation coefficient in statistical terms is zero.

12. Gender and Water

Since the 1970's, international agencies have promoted the participation of women in water management and improvement of use efficiency and conservation as a way to increase health conditions and reduce poverty. Consequently, Mexico recently included elements in its policies to achieve gender equity regarding the access to, and control of, water (Nazar et al., 2010). Nevertheless, in many areas this has not occurred in practice.

An example is Chiapas, a state which has almost two thirds of the nation's surface water, and nevertheless contains rural and especially indigenous areas where water services are lacking. In these areas water is often obtained from sources such as pits, that are frequently polluted (84.5% of this water is not fit for human consumption due to its poor bacteriological quality), and lack water in the dry season. As a consequence, not only does water come at a high cost, which for women often implies walking up to 3 hours to fetch it; but also water needs are frequently used as an instrument to exert control and pressure to form part of religious and political groups, and form part of conflicts between municipalities. Similar situations can be observed in states, where issues are also brought about by pollution problems. Other examples occur in the north and center of Mexico, where water scarcity is greater and the cost is higher. Again women and children suffer the most as they must carry water large distances, and employ many hours in the process (Nazar et al., 2010).

Table 14. Indexes of Marginality, Water Supply and HDI.

Federal Entity	% illiterate population age 15 years or more	% population without full elementary education age 15 years or more	% dwellers in houses without sewers or sanitary utilities	% dwellers in homes without electric power	% dwellers in homes without piped water	Drinking water supply (l/h/d), 2007*	Human Development Index (HDI) 2004**
National	8.37	23.10	5.34	2.49	10.14	278	0.8031
Aguascalientes	4.16	17.82	1.68	0.85	1.79	318	0.8271
Baja California	3.08	15.02	0.56	1.49	4.89	258	0.8391
Baja California Sur	3.62	16.49	1.84	2.88	11.28	440	0.8332
Campeche	10.20	26.96	9.85	4.85	11.15	487	0.8263
Chiapas	21.35	42.76	8.07	5.88	25.90	209	0.7185
Chihuahua	4.42	18.81	3.29	4.28	6.45	455	0.8340
Coahuila	3.29	14.60	1.65	0.77	2.17	325	0.8356
Colima	6.42	21.58	0.80	0.67	1.66	437	0.8097
Federal District	2.59	9.70	0.16	0.15	1.51	367	0.8837
Durango	4.84	22.92	8.51	3.52	8.63	429	0.8045
Guanajuato	10.44	28.80	9.87	1.93	6.14	244	0.7782
Guerrero	19.88	35.98	27.18	6.33	31.34	209	0.7390
Hidalgo	12.80	27.50	8.98	3.90	12.21	153	0.7645
Jalisco	5.56	21.30	2.42	1.12	5.91	271	0.8036

12.1 Gender and Water for Agriculture

Although the Agrarian Reform Act of 1971, recognized that men and women are equal regarding land ownership, this has yet to occur in practice. In 1990 there were 3.1 million owners of ejidos (common lands) throughout the country, of which less than 46,000 (nearly 1.4%) land deeds belonged to women. There are no data on how many of these had access to irrigation, although in general, women rarely participate in irrigation units or hold water concession deeds (Nazar et al., 2010). In 2002, the Ministry of Agrarian Reform created the Programa de la Mujer en el Sector Agrario (Program for Women in the Agricultural Sector, or PROMUSAG), with the aim of supporting farming projects for women with agrarian rights; it includes 661,000 women who own ejidos and common lands. Only 1.36% of women with agrarian rights, benefit from this program and it remain unclear if their access to water is sufficient. Thus, in the same way as women have traditionally been excluded from owning

Table 14 (Cont.) Indexes of Marginality, Water Supply and HDI.

State of Mexico	5.32	16.24	4.76	0.96	6.04	241	0.7871
Michoacán	12.58	33.48	5.66	2.11	9.97	237	0.7575
Morelos	8.13	21.01	3.10	0.81	7.84	527	0.8011
Nayarit	8.02	26.05	6.78	4.38	8.35	256	0.7749
Nuevo León	2.78	12.70	0.54	0.56	3.48	266	0.8513
Oaxaca	19.35	38.49	6.84	7.21	26.29	106	0.7336
Puebla	12.71	29.02	5.45	2.19	14.03	156	0.7674
Querétaro	8.14	20.03	9.95	2.99	5.76	275	0.8087
Quintana Roo	6.58	19.42	5.19	2.59	4.66	169	0.8296
San Luis Potosí	9.92	27.42	5.72	5.58	16.97	186	0.7850
Sinaloa	6.42	23.42	5.14	1.92	6.24	352	0.7959
Sonora	3.73	17.21	1.92	1.87	4.01	488	0.8253
Tabasco	8.57	25.10	3.99	1.95	22.94	220	0.7800
Tamaulipas	4.52	18.61	0.84	2.88	4.26	337	0.8246
Tlaxcala	6.68	18.78	4.84	1.11	2.03	182	0.7746
Veracruz	13.42	32.90	4.18	4.67	23.32	279	0.7573
Yucatán	10.89	29.99	17.96	2.61	3.03	352	0.7831
Zacatecas	7.20	30.83	10.53	1.91	6.72	408	0.7720

Note: CONAGUA. 2007, Situación del subsector agua potable y alcantarillado, P. A-2. ** PNUD-México, 2007, Informe sobre Desarrollo Humano, México 2006-2007: migración y desarrollo humano, p. 166.
SOURCE: Montesillo et al., 2010

land, they are also excluded from water rights (Nazar et al., 2010).

The Blue Agenda for Women (La Agenda Azul de las Mujeres), (2006) points out that in recent years, the policies for decentralization of water management in Mexico found in the National Water Law[3] (2008), have not increased financial, technical and human institutional capacities in women. Dávila-Poblete (1998, 2000) analyzes how poor women in Mexico are losing their water rights as a consequence of the transference of irrigation district management.

With the appearance of new user associations registers, water will be assigned to whoever works the land and not to he or she who owns it. Although many women do not work the land they own, they nevertheless have had authority regarding the use of water. This is currently changing under the new structures. Women have limited participation in the making of public decisions due to their confinement to the household, and the disadvantages they have within communities as a consequence of patrilocal marriage rules. Although the law stipulates that the participation of users must be promoted in various organizational areas, women are excluded because water rights are not to their names and thus their access to irrigation water is informal. The law itself does not exclude them, but deeds and traditions do, and they also marginalize themselves from decision-making organisms (Nazar et al., 2010). In order to guarantee the participation of women, it has been suggested that they should be included in technical sessions and decision-making as well as in the agencies in charge of water policies in the country, such as CONAGUA, as control of water resources is transferred from state to localities.

13. Poverty

13.1 National Situation

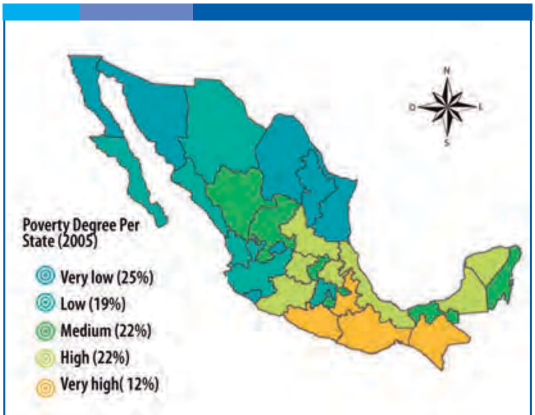
In Mexico, 22 million people still lack access to sewage systems and 3 million lack drinking water services; most of these have low income and are greatly vulnerable (Guevara et al., 2010). According to poverty limits (CONEVAL, 2007)[4] it has been calculated that until 2006, 14% of the population suffered nutritional poverty, 21% human capacity poverty and 43% income poverty. FIG. 18 shows a graph of poverty degree per state.

13.2 Water and Absolute Poverty

FIG.19 presents the percentage water services for rural and urban populations with respect to the presence of nutritional poverty. The differences are clear and a discrepancy between poor homes in rural and urban areas can be observed as 70% of poor rural households have access to water services compared to

3 Chapter I, Article 5, Paragraphs II and III, as reformed on April 29, 2004, states that it "shall promote the participation of water users and private individuals in the performance and management of hydraulic works and services", and "shall favor the decentralization of the management of water resources, according to the current legal framework", respectively.

4 As stated by CONEVAL (2007), and according to monthly income per capita in August of 2006, three kinds of poverty can be defined in rural areas: nutritional poverty (598.7 pesos), human capacity poverty (707.84 pesos) and income poverty (1,086.4 pesos), these same categories, but in urban areas are determined by 809.87, 993.31 and 1,624.92 pesos, respectively.

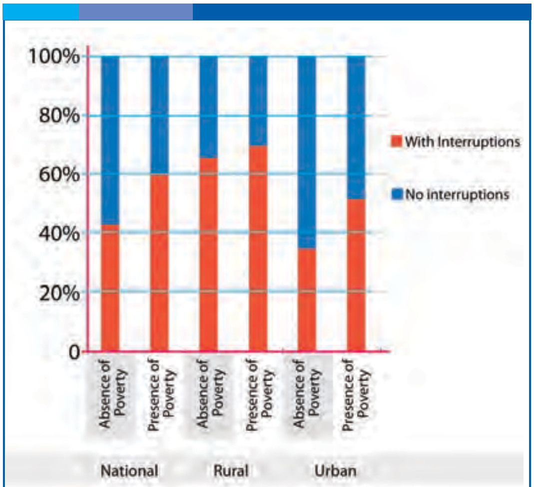


SOURCE : II CONTEO DE POBLACION Y VIVIENDA 2005. INEGI. ÍNDICE DE REZAGO SOCIAL, CONEVAL.

FIG. 18. Degree of Poverty per State

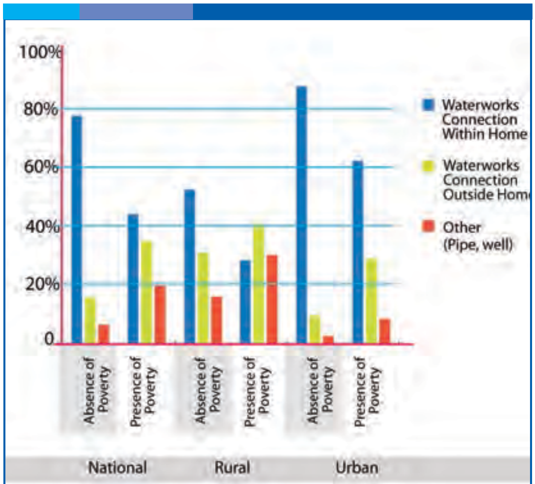
50% of poor urban homes (Guevara et al., 2010). Poverty is also related to access to public infrastructure for water supply.

FIG. 20 shows how homes where there is no poverty are more likely to have access to public waterworks within the home, while it is more probable for a poor home to obtain its water from a waterworks connection outside the home, or through other sources such as tank trucks, wells, rivers, or another home. Again the mostly clearly marked difference is between rural households in nutritional poverty and urban homes without nutritional poverty, as only one in every three poor rural households has a waterworks connection inside, while nearly 90% urban non-poor homes do have this service (Guevara et al., 2010). With respect to sewage, only 30% of poor homes in rural areas are connected to a sewage system, while sewage service coverage for urban non-poor homes is greater than 90% (FIG. 21). It is worth mentioning that 38% of poor rural homes have no access to sewage systems at all and thus must face adverse conditions and probably suffer greater health risks and contamination of water sources. Finally, FIG. 22 shows that the percentage of the total income spent on water is greater in poor homes than in those that are not poor.



SOURCE: GUEVARA ET AL., 2010

FIG. 19. Frequency of Water Services in Households According to Presence or Absence of Nutritional Poverty (‹ $598.70).



SOURCE: GUEVARA ET AL., 2010

FIG. 20 Source of Water in Households According to Presence or Absence of Nutritional Poverty.

This difference is more noticeable in urban areas where a poor home spends on average 3.4% of its total expenses on water, compared to 1.8% in a non-poor home. In other words, in urban areas, a poor household spends nearly twice as much (in relative terms) as a non-poor household.

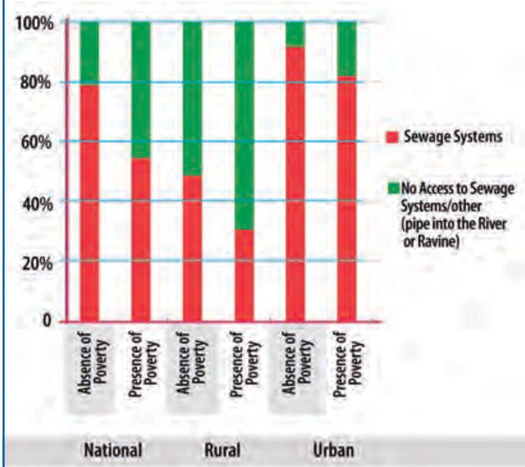
Nationwide, this relationship is 1.7 to 1 and 1.6 to 1 in rural homes; thus, poor homes must sacrifice a larger portion of their income to satisfy their water needs than a home that is not poor. These data only refer to direct costs for services; nevertheless, as already mentioned, water services are often interrupted and at times, water quality is questionable. Buying bottled water is one of the most expensive measures to ensure drinking water quality.

The high use of this type of water could be related to various aspects such as the world-wide growth of the sector, but there is also evidence of a relationship between purchasing bottled water and deficient water services, especially regarding programmed supply at specific periods, poor quality or lack of trust in water quality. For this reason, the amount spent on bottled water is greater in poorer homes, as already stated above (Soto, 2007).

13.3 Water and Relative Poverty

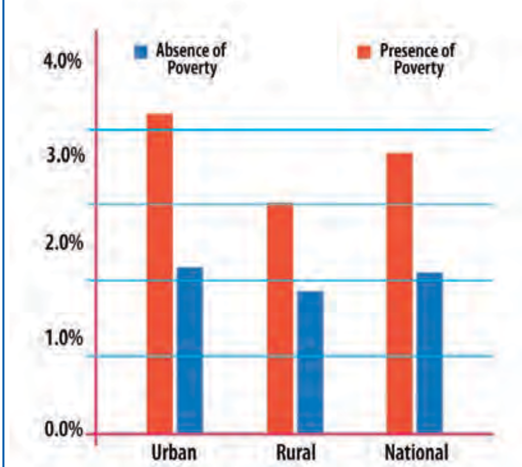
Guevara et al., 2010 built a water service backlog index considering the percentage of private dwellings (VPH -viviendas particulares habitadas) that lack: (a) a lavatory or toilet, (b) piped water from public networks and (c) drainage.

As a result, there are five backlog categories (very high, high, medium, low and very low). FIG. 23 shows that backlog in water services is mainly correlated to levels of nutritional poverty. In addition it was found that localities with these two traits also have low indexes of education and health.



SOURCE: GUEVARA ET AL., 2010

FIG. 21. Sewage Availability in Private Households According to Nutritional Poverty.



SOURCE: GUEVARA ET AL., 2010

FIG. 22. Water Cost as a Proportion of total Expenses in Private Homes According to Nutritional Poverty.

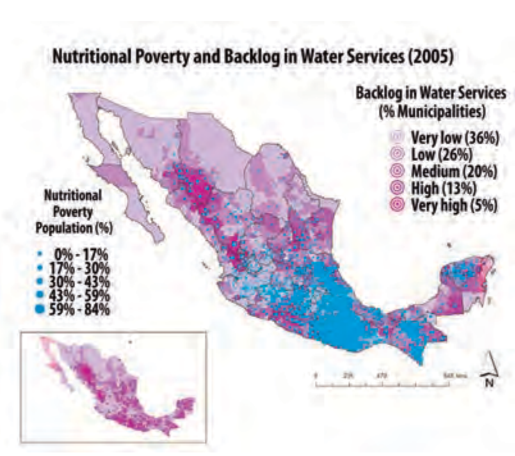
13.4 Water Services and Education

According to Guevara et al., 2010, the Ministry of Education (SEP - Secretaría de Educación Pública) has identified schools with the greatest infrastructure needs using, among other criteria, the condition of school lavatories. FIG. 24 presents the degree of marginalization and the corresponding state of lavatories in schools with infrastructure needs. As can be noted, the degree of marginalization is correlated to the poor state of sanitary facilities, which in a way confirms that the most marginalized population (and the poorest) is the one dealing with this issue. Thus, the lack of adequate sanitary infrastructure in schools is a problem that mainly affects children from poor homes. As has been recognized by UNICEF (2006), unhygienic living conditions and the lack of access to clean water have a negative impact on the health, school attendance and learning capacity of schoolchildren. The above is a clear example of how the various manifestations of poverty are intertwined and generate a trap that hinders improvement in the quality of life of people.

14. Water and Indigenous Population

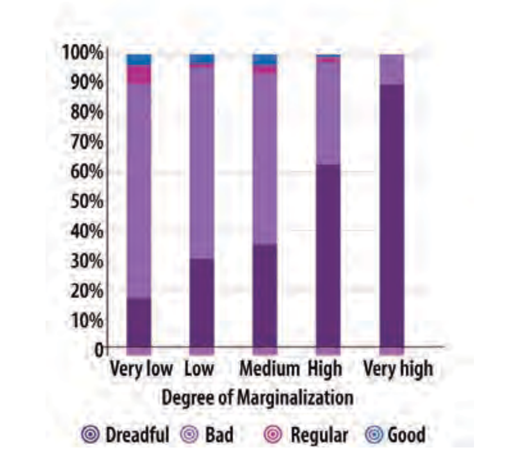
Mexico has great ethnic and linguistic diversity. In 2005 more than 10 million indigenous people speaking over 62 languages where registered throughout the entire country, but especially in the central and southern states (INEGI, 2005). In order to evaluate the importance of Indigenous peoples in water management, it is necessary to consider the land they live on, work and govern. The debate on these territories was opened during the zapatista insurrection in 1994, and although it is still to be resolved, it is still manifest in the various perceptions of the political construction of the autonomy of indigenous peoples in Mexico (Peña et al., 2010).

Unfortunately, not all participants have been considered equally in the federal policies on



SOURCE: GUEVARA ET AL., 2010.

FIG. 23. Nutritional Poverty and Backlog in Water Services.



SOURCE: GUEVARA ET AL., 2010

FIG. 24. Degree of Marginalization with Respect to the State of Lavatories in Schools with Deficiencies in Infrastructure.

water management. To the present date, indigenous peoples and communities have been invisible with regards to the design and practice of these policies notwithstanding the large volumes of water that fall on their land which feed the nation's aquifers and currents, and the extremely important role they play in the conservation of vegetation coverage of the elevated areas of watersheds (Peña et al., 2010).

Indigenous populations and their local governments are key factors in hydrological conservation as they sustain soil and the overall health of water sources and currents in areas of precipitation and recharge.

These activities still require the native knowledge these peoples possess. There are plenty of examples that prove that indigenous peoples know how to defend their natural, territorial and water patrimony in highly adverse conditions in which they confront social stakeholders with enormous economic resources and political influence. The main problem is that there are no policies to incentivize and reinforce native knowledge and it therefore it can be lost (Peña et al., 2010).

15. Transboundary Water

15.1 Northern Border

The state of Baja California is found in the upper northwest of the Republic of Mexico, within the territorial strip characterized by arid and semi-arid regions. Although the region corresponds to the area where the world's major deserts are found, with their characteristic scarcity of water for human consumption, the lack of water has not been a limiting factor for the social and economic development of one of the most important economic regions in Mexico. Here, nearly 4 million people from throughout the country have established their livelihood, forming a mosaic of cultures, traditions and customs that have given rise to a new community on Mexico's northern border (Román et al., 2010).

The main source of water is the Colorado River containing a volume provided annually by the American government in accordance to the International Waters Treaty of 1994 (Box 1). This water supplies the municipalities of Mexicali, Tecate and Tijuana in the state of Baja California and the municipality of San Luis Río Colorado in the state of Sonora for human use and productive activities.

Box 1

Treaty on the International Waters between Mexico and the United States of America. With information from Martínez et al., 2010.

The Treaty determines that Mexico delivers water from the Rio Grande to the United States, while Mexico receives water from the Colorado River from the US. In addition, it specifies that water delivery is accounted for in five-year cycles and "in the case of extraordinary drought, any missing flow will be replaced during the following cycle". However, the term "extraordinary drought" is not explicitly defined in the treaty (Martínez et al., 2010). To define this term, first it must be stated that a year is considered to be dry if the sum of virgin flow (uncontrolled) is less than 3,388 million cubic meters (Mm^3), or the average annual flow registered. Likewise, a five-year dry period can be defined as one in which the sum of virgin flows is less than 16,940 Mm^3 (five times the average) in five years. Because the flow to be delivered to the United States per five-year period is 2,158 Mm^3 and the anticipated water volume for use in Mexico in this same span is 9,825 Mm^3, an "extraordinary drought" could be considered to occur when the five-year virgin flow is less than 11,983 (2,158 +9,825) Mm^3 (representing 71% of the average five-year flow), which implies that the sum of the surplus from the six tributaries is equal to or less than zero.

Another source of water is the aquifer beneath the Mexicali Valley, recharged by infiltration of the Colorado River as it flows to the Gulf of California (Román et al., 2010). In this area, the relation between the two nations acquires an additional dimension, as the population of both countries shares the use of water. Not only are the frequent droughts a cause of a variety of conflicts, but also flooding caused by a lack of infrastructure for control when precipitation is intense. Based on an analysis of water availability for the five municipalities in Baja California, it can be stated that only Mexicali has a permanent volume of water sufficient to cover the demand of the majority of the population during the entire year.

Baja California receives 1,850,234 Mm^3/ per year from the Colorado River, equal to 9.1% of its annual base flow, which is entirely controlled by the US government (CILA, 2000). Not all water provided has the same quality as 10% is highly saline and is inadequate for direct agricultural use.
To deal with this technical problem, the Mexican government has set up a procedure in a place called "La Licuadora" to mix these waters with those from the aquifer in order to reduce the total salt concentration and adapt it for productive purposes. In a way, both nations have helped solve the problem regarding the amount of water, although quality, which is not dealt with clearly in the aforementioned Treaty, has become a problem. (Román et al., 2010).

The situation of the transboundary watershed with the United States is of even greater concern in the face of the possible effects produced by climate change, especially because greater drought is expected in the area in the future. An increase in temperature and a decrease in precipitation would result in more frequent and more severe hydrological droughts, as can already be observed in the transboundary watersheds between Mexico and the United States. To a great degree, the problem has become more acute because of the important increase in urban and industrial consumption, not so much due to a fall in the contribution of the river basins. (Roman, et al, 2010).

15.2 Southern border (Mexico, Guatemala and Belize)

Water is ubiquitous along the border shared by Mexico, Guatemala and Belize. Most of the Mexico-Guatemala boundary is fluvial (53%) and corresponds to the Suchiate and Usumacinta rivers, while nearly the entire Mexico-Belize international boundary (87%) is determined by the Hondo River. Various wetlands and numerous transboundary rivers of various sizes extend along both sides of the international boundary between Mexico and Guatemala in addition to the three aforementioned international rivers. Some small lakes and lagoons are artificially divided by the border, as well as groundwaters the transboundary connections of which have yet to be studied in detail. This variety of flows and bodies of water form six transboundary river basins, two running to the Pacific Ocean, three into the Gulf of Mexico, and one into the Caribbean (Kauffer et al., 2010). Despite the above, the Southern border appears to hold little importance for the Mexican government and its southern neighbors. Thus, information about water uses, pollution and extraction is hard to come by, particularly from Guatemala and Belize. On the other hand, although there is more information available in Mexico, its use is difficult as it is available by province or hydrological region, rather than by river basin (Kauffer et al., 2010).

Overall, water availability is not a problem for the Southern border area in terms of quantity and quality, however the gap in basic water and sanitation services, particularly in indigenous areas, is enormous (Kauffer et al., 2010). Although the area contains six transboundary river basins, cooperation regarding the sharing of water between nations is virtually absent. This situation contrasts with the richness of transboundary water exchanges on a local scale.

15.2.1 Transboundary river basins between Mexico, Guatemala and Belize

Oregon State University identifies the Suchiate, Coatan, Grijalva, Candelaria and Hondo transboundary river basins in this region. A closer analysis (Kauffer et al., 2010) reveals the existence of six basins instead of five and the absence of official demarcation of transboundary river basins between Mexico, Guatemala and Belize as a consequence of a the lack of consensus among their governments. Four of the six transboundary river basins that have been identified are binational (shared by Mexico and Guatemala), while two cross boundaries between Mexico, Guatemala and Belize. The four binational basins correspond to the Suchiate, Coatan, Grijalva and Candelaria rivers, and the trinational ones are the Usumacinta and Hondo rivers[5]. Data for these river basins are shown in Table 15.

The six transboundary river basins cover a total area of 167,725 km^2, i.e., slightly more than 1.5 times the extension of Guatemala, about seven times the size of Belize and more than twice the size of the state of Chiapas. For Guatemala, managing transboundary basins represents agreeing with Mexico and Belize to put into order or to intervene more than half of its territory; while for Belize it corresponds to one fifth of its territory, and finally for Mexico, it is only a minimal part (Kauffer et al., 2010).

Thus, Mexico should be the most interested party in the management of its shared basins for two concrete reasons: approximately 40% of the surface waters of the country flow through these southern transboundary river basins, and the entire Mexican territory in these river basins are located downstream. In spite of the territorial and hydrographic continuity of the six river basins and the importance due to their flow volumes, national policies remain strictly centered on national interests.

The main cooperation mechanism in Mexico related to boundaries and water issues at the Southern border is the International Boundary and Water Commission (CILA -Comisión Internacional de Límites y Aguas), which belongs to the Ministry of Foreign Relations. It is a binational commission with counterparts in Guatemala and Belize, as well as Mexico. The Mexico-Guatemala International Boundary and Water Commission were established in 1961 while the Mexico-Belize International Boundary and Water Commission was created in 1993. In 1990 Mexico and Guatemala signed the treaty for the consolidation of the Mexico-Guatemala International Boundary and Water Commission, which was ratified and published in 2003. CILA's work in the three countries has basically consisted of fixing the international river boundaries and demarcating the agreed land boundary between Mexico and its neighbors –established by treaties of 1882 between Mexico and Guatemala and of 1893 between Mexico and British Honduras (today Belize)- with monuments and a dirt road.

The contemporary dynamics of negotiation between Mexico and Belize are intended to achieve an agreement to demarcate the blue stream boundary (located upstream in the Hondo river basin) in a wetlands area which disappears during the dry season. The problem deals with the fact that the boundary was established in 1893 following the European method called thalweg used for navigable rivers, which is the deepest channel. The decreasing water quantity of wetlands provokes the "evaporation" of the thalweg and consequently of the international boundary. In the Suchiate River, the concern is related to the river mobility which not only generates floods but also moves the boundary between Mexico and Guatemala as defined by the thalweg.

In response to this issue, during six decades both governments have unsuccessfully tried to drive the river back to its bed. A binational or trinational agreement on transboundary waters and management of shared river beds

Table 15 Characteristics of Southern Border Transboundary River Basins.

River basin	Area km^2	Number of localities	Number of inhabitants	Inhabitants/km^2	Forests and jungles (% of total surface area in km^2 per river basin)
Suchiate	1,230	749	274,347	223.04	23.73
Coatan	733	369	103,090	140.64	23.87
Grijalva	56,895	15,144	4´804,794	84.45	42.63
Usumacinta	73,192	9,058	2´353,842	32.15	45.24
Candelaria	20,816	1,547	114,276	5.48	61.66
Hondo	14,859	213	88,145	5.90	66.00
Total-average	168,349	27,198	7´803,727	46.35	47.80

Source: Kauffer et al., 2010

5 It is important to mention that only a very small part of the Usumacinta river basin belongs to Belize (16 km^2).

is not a priority for the three nation states within the dynamics of national sovereignty centered on the establishment, demarcation and ratification of the shared boundary (Kauffer et al., 2010). Attention has not been paid to transboundary river basin issues by CILAs, which do not have the necessary competence, and Mexico has not signed treaties on waters with its two neighbors. These agreements are unthinkable today in the light of statements issued by the Guatemalan government. Guatemala points out that it will not sign any international convention or agreements with neighboring countries because it will not commit to put the sovereignty of "its" natural resources, including waters, at risk. This statement emphatically stresses that Guatemala produces water, 60% of which flows to Mexico, El Salvador, Belize and Honduras (Colom, 2009), and it is not willing to negotiate water quantity or quality with its neighbors (Kauffer et al., 2010).

Today, deforestation processes in transboundary river basins contribute to soil collapse and river sedimentation which provoke huge floods in five of the transboundary river basins (Suchiate, Coatan, Grijalva, Usumacinta and Candelaria). Likewise, water pollution derived from lack of water treatment, solids waste, use of agrochemicals, mining (Grijalva, Suchiate and Coatan) and oil industry pollution (Grijalva and Usumacinta in the state of Tabasco in Mexico and in the Peten department of Guatemala) is not subject to study nor considered an important issue by the countries involved.

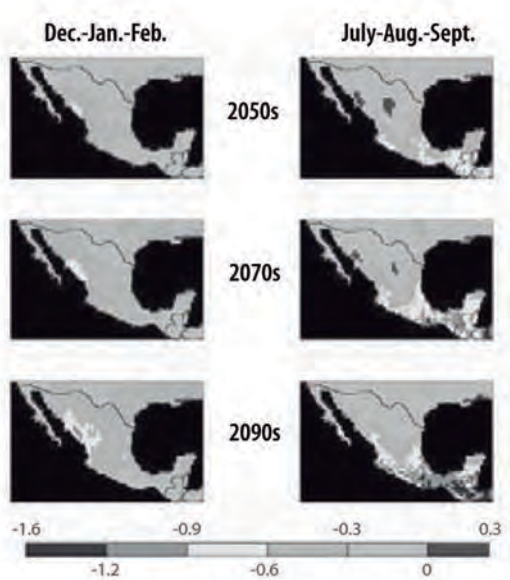
In the Hondo River the main problem is the discharge of wastewater and used waters from sugar cane agroindustries located in Quintana Roo, Mexico and in Orange Walk, Belize (Kauffer et al., 2010). Finally, a serious issue for all three countries will be climate change. Transboundary river basins are located in a continental strip of 500 kilometers between the Pacific Ocean, the Gulf of Mexico and the Caribbean, i.e. a path for potentially strong hurricanes. During the last twenty years, eight hurricanes provoked huge economical, agricultural and infrastructure damages in the transboundary river basins, including loss of lives (Kauffer et al., 2010). Cooperation related to transboundary waters oriented to forest, land use and water management and centered on territorial planning of productive activities and human settlements is today a pressing need to face a variety of vulnerabilities associated with climate change along this shared boundary.

16. Climate Change

A regional analysis using interpolation systems derived from results obtained from general circulation models shows that Mexico will present significant and unprecedented increases in average temperature during this century.

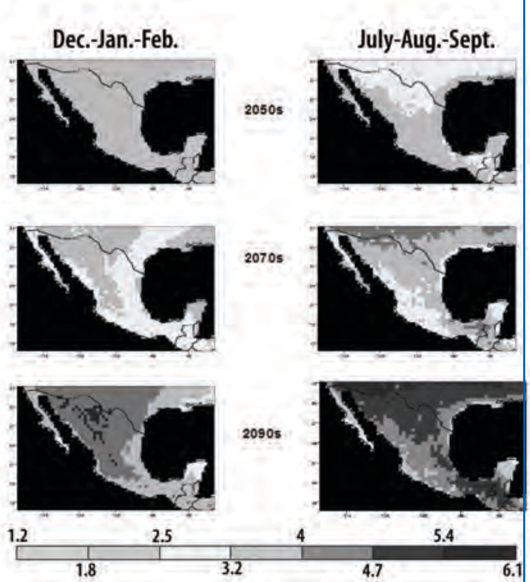
Towards the end of the century, if sufficient mitigation measures are not adopted worldwide, the increase in temperature may reach 4°C, with potentially catastrophic effects on the environment and productive activities. In such a scenario, water resources in Mexico will be severely affected. In general, a negative combination of reduced water availability caused by reduced precipitation in most parts of the country and greater evaporation from soil and natural vegetation is expected, together with other increases in water demand (Martinez et al., 2010). FIG. 25 shows average precipitation anomalies (in mm/day) for winter and summer months in the decades of the 2050s, 2070s, and 2090s.

As can be observed, it is generally estimated that total precipitation will decrease gradually in upcoming decades throughout most of Mexico (as compared to 1961-1990 climatology). In the winter, this can be especially seen in the northern and western regions of the country; and in the summer, in the central and southeastern regions. It should also be observed that by the mid 21st century, positive anomalies are expected in the summer in small central, northern, and northwestern regions of the country; nevertheless, it should not be overseen that as the century progresses these anomalies tend to invert themselves. As for surface temperature, the results are shown in FIG. 26. As can be seen, positive anomalies are shown for the entire country, which imply higher temperatures than in the 1961–1990 baseline period. In addition, a gradual increase is seen in temperature as time progresses, especially in the summer months in the northern and southeastern parts of the country, where anomalies close to 5°C are estimated for the last decade of the century. In particular, water demand for irrigation will increase if irrigation systems are not upgraded or if irrigation areas are not reduced. Irrigation consumes around 77% of available water resources in Mexico. Foreseeably, natural aquifer recharge will decrease, which in turn will increase the pressure on overdrafted aquifers and on those currently in balance. FIG. 27 shows the aquifers that are currently overdrafted and which are located in the regions where there



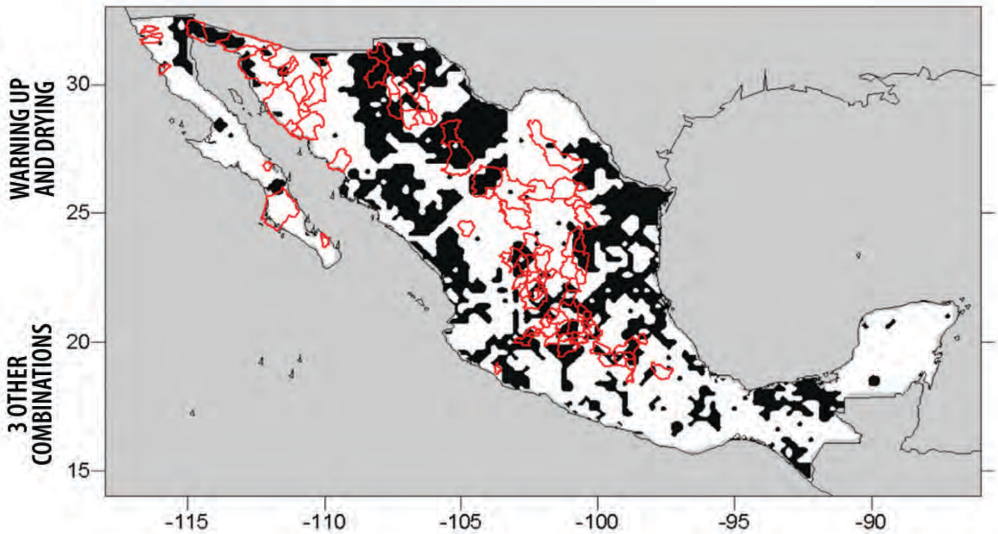
SOURCE: MARTÍNEZ ET AL., 2010

FIG. 25 Average Precipitation Anomaly (mm/day) Regionalized with the REA Method for Scenario SRES-A2 in Relation to the 1961-1990 period.



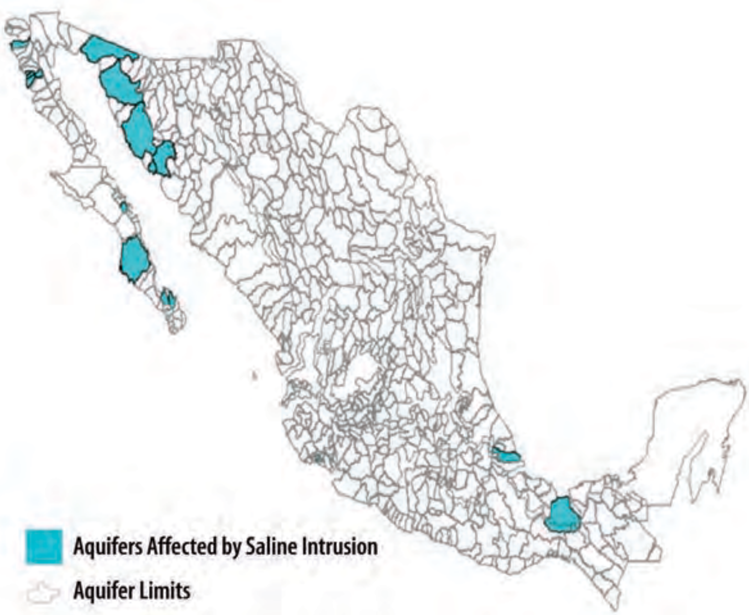
SOURCE: MARTÍNEZ ET AL., 2010

FIG. 26 . Surface Temperature Anomaly (°C) Regionalized with the REA Method for Scenario SRES-A2 in Relation to the 1961-1990 period.



SOURCE: ARREGUIN ET AL., 2010

FIG. 27. Overdrafted Aquifers in Regions that Will Have Temperature Increases and Precipitation Decreases



SOURCE: MARTINEZ ET AL., 2010.

FIG. 28 Overdrafted Aquifers on the Coast under Saline Intrusion Risk Due to Sea Level Rise will be lower recharge into the subsoil and greater water evapotranspiration, while FIG. 28 shows the aquifers that will experience greater problems due to saline intrusion. Thermal stress caused by global warming will diminish the productivity of some of the most important crops in Mexico, which will also alter their phenological cycle. Temperature increase will also enhance the tendency towards eutrophication in lakes and reservoirs. The main challenge lies in incorporating the effects of climate change into the planning and management of water resources. In general terms, the water sector in Mexico should make an enormous and costly effort to adapt to climate change. This will require deep institutional and legal changes that can translate into a more efficient and sustainable management of water resources (Martínez et al., 2010). Therefore, it is deemed necessary that the country invest more in research and development in the field of climate change; that commitment-binding mechanisms are established among all those involved with this phenomenon; and that Mexican data and models be used in scenario-development processes.

17. Extreme Contingencies

17.1 Overall Situation

As a consequence of its geographic, orographic and hydrologic situation, Mexico is exposed to the possibility of extreme contingencies. Every year, from the beginning of May to the end of October, there are up to ten tropical storms, four or five of which turn into hurricanes that impact on either the Pacific or the Atlantic coast. The swellings of the main rivers cause important flooding in plains and low-lying towns. In small river basins, the swellings tend to be very quick and water flows at speeds that can cause human casualties. On the other hand, there are periods of scarce precipitation and low river levels that lead to drought, especially from November through April, particularly in the central and northern areas of the country, producing effects reflected in low agricultural production, death of livestock, problems to supply water, etc. (Arganis et al., 2010).

17.2 Institutional Capacity

In the year 2000, the Fund for Naturals Disasters (FONDEN) of the Ministry of the Interior was created to deal with the effects of natural, unforeseeable disasters, with magnitudes that surpass the financial capacity to respond of federal organizations. In 2003 the Rural Population Affected by Climate Contingencies (FAPRACC) of the Ministry of Agriculture, Livestock, Rural Development, Fishing and Feeding, was created and in 2008 it became the Program for Attention to Climate Contingencies (PACC).

The objective of the PACC is to support low-income farming and fishing producers so they may return to their productive activities in the shortest possible time in the presence of rare, relevant, nonrecurring and unpredictable climate contingencies. As from the year 2000, the National Center for Disaster Prevention (CENAPRED) analyzes the socioeconomic impact of geologic, hydrometeorological, chemical and sanitary phenomena. Out of a total 11576 events declared by FONDEN and PACC between 2000 and 2008, 96.9% were hydrometeorological, 1.6% chemical, 1.1% geologic and 0.3% sanitary (Arganis et al., 2010).

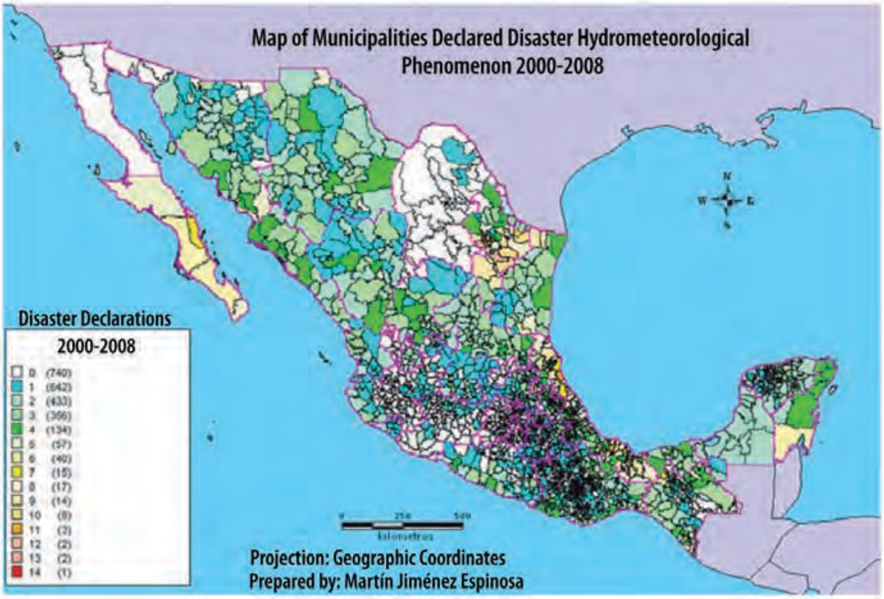
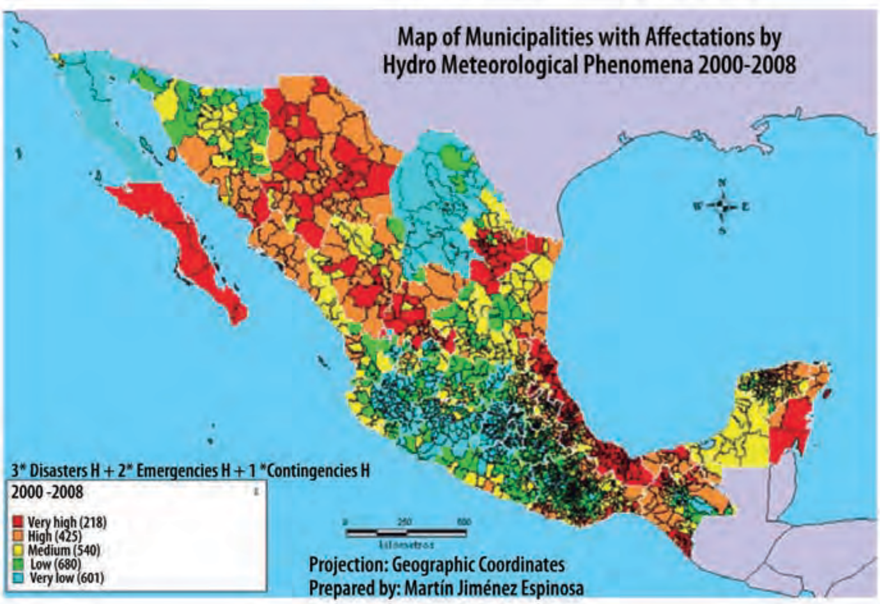


FIG. 29. Number of Disaster Declarations by Hydrometeorological Phenomena in Municipalities of the Country



SOURCE: ALANÍS ET AL., 2010)

FIG. 30 Combination of Declarations of Disasters, Emergencies and Contingencies by Hydrometeorological Phenomena in Municipalities of the Country

FIG. 29 shows a map of the main municipalities that have been declared in disaster by hydrometeorological phenomena in the same period. It is interesting to notice that the municipality with the greatest number of disaster declarations is Guadalupe, in the state of Nuevo Leon, with 14 (1.6 per year), notwithstanding its location in a zone of low annual precipitation. Most of the declarations of disaster in Mexico have been due to tropical cyclones (40%), followed by rains (33%), and thirdly by droughts (21%). The rest are due to low temperatures, tornados, snowstorms, frost or hail.

Arganis et. al., 2010 grouped all hydro-meteorological phenomena together and assigned a greater weight to disasters, less to emergencies and much less to climatologic contingencies, to obtain the map in FIG. 30, which gathers affectations by excess of rain as well as by water shortage. It is observed that Baja California Sur, Chihuahua, the south of Sonora and north of Sinaloa, Durango, Zacatecas, Nuevo Leon, Veracruz, Tabasco, Chiapas and Quintana Roo are the states with greatest difficulties.

17.3 Floods

Luckily, floods caused by insufficient works and control have been not too frequent. Nevertheless, there have been important floods, as shown in Table 16.

In spite of the problems caused by floods (FIG. 31), since the mid 80's the development of infrastructure for flood regulation has been reduced, and the deterioration in maintenance and operation of hydrometric and climatologic alert networks is remarkable. These have also reduced their coverage (unfortunately, from the 70's to the present, the number of (STREAM) hydrometric and climatologic gages have fallen noticeably and the incorporation of digital measurement technology has been almost null). In addition, maintenance of meteorological radars installed by the National Commission of Water (CONAGUA) 10 years ago has deteriorated and only one new radar has been installed in the state of Chiapas. It is necessary to extend the number of early warning systems, incorporate precipitation-runoff models that are correctly calibrated and guarantee their suitable operation at all times.

17.4 Extreme meteorological phenomena

The impact of tropical cyclones on the availability of water is such that it produces most of the moisture that the sea carries towards the mainland, although it also causes great flooding problems. From 1970 to 2008, the Mexican coastline was hit by 170 tropical cyclones, and although they caused major damage given the vulnerability of many Mexican regions, they left large amounts of water, filling dams and natural lakes and providing humidity to much of the national territory. In contrast, droughts occur in many regions of the country causing great economic loss, especially in agricultural and livestock regions.

18. Water Management

In the past 25 years the Mexican State has implemented a profound process of change in the management of water with basis

Table 16. Events That Have Generated Greater Damage by Flooding

YEAR	EVENT	STATES	DEATHS	AFFECTED POPULATION	TOTAL DAMAGES (Millions of dollars)	COST or RAIN	DESCRIPTION
1943	Winter Rains	Sinaloa	27	600	$0.14	14,376 m^3/s, Fuerte River, Huites hydrometric gage station.	11 rivers overflowed; most important in Tamazula, Humaya, Fuerte, Sinaloa and Culiacán. The North part of the state was isolated without communication by telephone and telegraphic media. Two railroad bridges, some sections of the South-Pacific railroad, several highways and houses were damaged. There were landslides. Losses in agriculture were numerous.
1949	Winter Rains	Sinaloa and Sonora	10	159,000	$10.20	5,265 m^3/s, Yaqui River, Eagle hydrometric gage station. 10000 m^3/s, Fuerte River, Huites hydrometric gage station. 6,390 m^3/s, Mayo River, Three brothers hydrometric gage station.	Overflowed Yaqui, Fuerte and Mayo rivers. More than 35 localities were flooded. At least 9,000 homes were damaged. Two bridges and roads were damaged. Cattle were lost. Many localities were isolated (Telegraph and telephone services were suspended). South Pacific rail service was temporarily canceled due to damage to railway lines. Álvaro Obregón dam, which was under construction, was destroyed almost entirely .
1955	Hurricanes: Gladys, Hilda and Janet	Veracruz, Tamaulipas, San Luis Potosí, Yucatán and Quintana Roo	110		7.5*	4,002 m^3/s, Tempoal River, Tempoal hydrometric gage station. 4,810 m^3/s, Tampaón River, Pujal hydrometric gage station.	Hurricane affected mainly the Pánuco River basin. There was flooding in low-lying areas of the city of Tampico, with a height of 3.30 m above average tide. The capacity of San José dam, in the State of San Luis Potosí was exceeded. The curtain did not fail. Part of the city of San Luis Potosí was flooded. A bridge that leads to the villages of Mezquitic and Ahualulco was damaged. The overflow of the Santiago River destroyed many houses in the village of Soledad Diez Gutiérrez. In Tampico and Madero City nearly 6,010 homes destroyed or damaged. Flooded area was estimated at 6,400 km^2 and 20,000 heads of cattle were lost.

1959	Manzanillo Cyclone	Colima and Jalisco	1,500	1,600	N/D	Three merchant ships were adrift with their crews; 25% of the houses were completely destroyed in Cihuatlan, and there were damaged roads and derailed trains.

N/D No rain and no runoff data
* Damages relating only to the city of Tampico

Source: Arganis et al. 2010 "Prevención", Fascículo "Inhundaciones" ("Prevention" Journal, Part "Floods", reports from socio-economic impact series and information from socio-economic studies.

on two core issues: on the one hand, the transformation of the legal structure for water governance, and on the other, an important decentralization process. This transformation implies an attempt to democratize water management by opening participation to water users[6], organized society and private companies. As a result, regional agencies, watershed councils and agencies, and their auxiliary organs have been created and

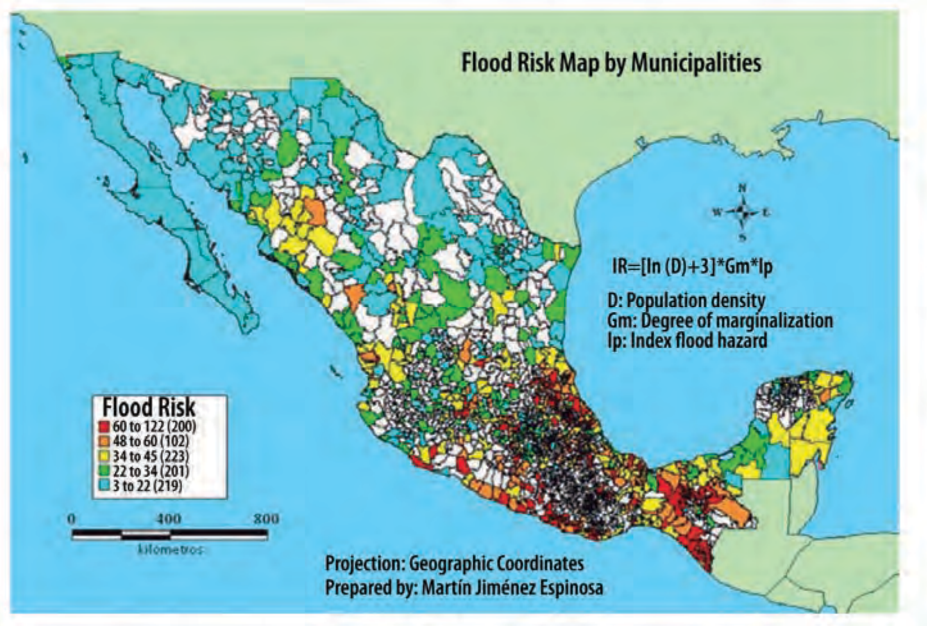


FIG. 31. Estimation of Flood Risk in Municipalities Throughout the Country (Jiménez, 2008)

6 The term 'user', as defined in the National Water Law, refers to the user of national waters, and is the moral or legal person that has a permit, concession or assignment from National Water Commission CONAGUA, to exploit or use national waters and their inherent goods.

strengthened. This has been achieved by creating and strengthening local authorities for water regulation and management, such as the offices of the Regional Agencies of the National Water Commission, and the creation of new environments for participation in the organization structure for water management such as Watershed Councils, the auxiliary organs of these Councils called Groundwater Technical Comities or COTAS and the transfer of Irrigation districts to users.

During these 25 years, water management and governance in Mexico has transformed from a model based on highly vertical and centralized administrative reasoning, to a model still in development which is less centralized and with a particular proposal for social and private participation, called by Aboites the "Commercial Environmental Model" (Aboites, L. 2009, 2010; Torregrosa et al., 2010).

The reforms have been centered on the areas administrated by the State, such as the irrigation Districts and Water Utilities, nevertheless these policies have left aside, what Aboites calls 'town waters' or 'aguas pueblerinas', that correspond to the 2.5 million ha of small irrigation and the huge amount of rural communities that manage on their own access to the resource to fulfill their needs.

18.1 Institutional Aspects

The evolution of the institutional framework is shown in Box 2. In 1989 The National Water Commission, CONAGUA, was created as the main water authority at the Federal level. It began as a decentralized agency of the Ministry of Agriculture and Hydraulic Resources, SARH, and in 1994 it became a decentralized agency of the Ministry of Environment, Natural Resources and Fishery or SEMARNAP, now the SEMARNAT.

The fact that by 2009 CONAGUA concentrated close to 72% of the budget assigned to this Ministry, gives an idea of the weight the agency has within the SEMARNAT. CONAGUA consists of a Technical Council, a General Director, an internal control agency and the corresponding administrative units. (Torregrosa et al., 2010).

18.2 Private Participation

The foundations for private participation policies in modern Mexico were established in the eighties, when the conditions necessary for the democratization of water and sanitation services in the country were created. These policies were the result of recurrent economic crisis that favored the submission of economic and social policies to the demands established by financial organisms such as The World Bank, International Monetary Fund, Inter-American Development Bank, among others.

The main idea behind them is that private participation allows a better and more efficient management of water and sanitation systems (Torregrosa et al., 2010). In Mexico, private participation occurred in some water services but mainly in sanitation systems. In general the private sector has participated in at least three main ways. (Torregrosa et al., 2010):

- The comprehensive management of systems, by which private companies that obtain a concession should invest and inject fresh private capital, although in reality they gain access to soft credits from the State. In Mexico there are two comprehensive concessions for water management, one in Aguascalientes and another in Cancun, one contract for the administration of the service in Navojoa, and a combined company with the participation of Aguas de Barcelona and the Municipality of Saltillo

• Administration through partial service contracts such as the ones in Mexico City and Puebla, among others. In these cases the government transfers the responsibility of part of the administration of the system without the need of capital investment

• Through construction, operation and transfer, the so called COT modality that has mainly taken place in the construction of treatment plants throughout the country.

18.3 Social Participation

Participation of society and water users in water management first occurred in Irrigation Districts towards the end of the eighties and during the nineties with the creation of users associations, and afterwards when the law established the participation of users and social organizations in Watershed Councils, and their auxiliary organisms such as Sub-watershed Councils and Groundwater Technical Comities or COTAS. In 1994 participation of the various users of water, such as agriculture, industry, services and water utilities in Watershed Councils was determined by law. During this phase, the number of participants in Councils acting

Box 2

Evolution of the institutional Framework, with information of Rodriguez y Emanuelli , 2010.

The institutional precedent of CONAGUA goes back to 1853, with the creation of the Ministry of Public Works, Colonization, Industry and Commerce, in charge of promoting agriculture and irrigation. In 1917, the Water, Land and Colonization Direction was created and in 1926 transformed into the National Irrigation Commission, CNI, mainly responsible for water management in the post revolutionary period. This Commission depended on the Ministry of Public Works and included in its functions to built and operate irrigation infrastructure, as well as design and implement irrigation projects and plans.

In 1947 and as a consequence of amendments to the Law of Ministries and State Departments, "water became a jurisdiction of the Ministry of Hydraulic Resources" and in 1970, responsibility of potable water was turned to the Ministry of Human Settlements and Public Construction (SAHOP). In 1976 the Ministry of Agriculture and Livestock (SAG) and the Ministry of Hydraulic Resources (SRH) were merged into a single agency, the Ministry of Agriculture and Hydraulic Resources (SARH). In 1980 SAHOP transferred some of water services to the state governments and in certain exceptional cases, states transferred these to municipalities. In 1982, The Ministry of Urban Development and Ecology becomes in charge of building and operating the water systems in the country.

From 1988 to the present, important changes have taken place in the country regarding water policy and management; "tending to change or cancel, most of the achievements and social rights obtained until then from inside institutional water structures". In 1989 and within this context and the framework of the first processes to liberalize water markets in Mexico, the National Water Commission or CONAGUA was created by president Carlos Salinas de Gortari. From the start, CONAGUA has played a fundamental role in water privatization in the country, although with limited success.

The creation of this new institution, in which integrates water management was centralized for the first time, was the response to several issues. One of these was the international tendency from 1990 oriented to restructure water management, requiring profound constitutional and institutional reforms, in most cases designed, supported and promoted by the World Bank and International Monetary Fund. Mexico followed these guidelines and began to analyze the modernization of governmental policies, specifically water policies. This institutional transformation has been very slow due to resistance from diverse areas and popular defense of water rights. In 2000 and in accordance to modifications to the Federal Law for Public Administration, the Ministry of Environment, Natural Resources and Fishery was divided into the Ministry of Agriculture, Livestock, Rural Development, Fishery and Food Supply (SAGARPA) and the Ministry of Environment and Natural Resources (SEMARNAT), which as previously stated, the heads CONAGUA.

on behalf of the government was greater than those representing users of all kinds. Consequently, and in spite of participation being open to users, the programming and coordinating of the comprehensive management of water remained concentrated in government authorities. In 1997, after having acquired experience and in response to demands from the various users of water and social sectors, the National Water Law regulations were amended and the internal structure of Watershed Councils was modified for the purpose of achieving a better balance between government and user participation.

The main effort in the formation of Watershed Councils and their auxiliary agencies occurred in 1997 when, within the institutional structure of CONAGUA, the Management for Watershed Council Coordination was created for the purpose of coordinating the general strategy for their creation. This strategy consisted of four phases: design, implementation, consolidation, and finally operation and development. Thus, from a single Watershed Council in 1993, we have today 25, in addition to 21 Watershed Commissions, 26 Watershed Committees and 78 COTAS throughout the country. (Torregrosa et al., 2010) . When the National Water Law was reformed in 2004, the legal framework for water management at the watershed level was strengthened and the social participation in councils was broadened. Therefore, for the first time participation at this level included organized society in general. These amendments established that representatives of the variety of users of water resources, together with society organizations, such as civil societies, must represent al least 50% of the participants in Watershed Councils. This reform also reinforced water management decentralization at the watershed level with the creation of Watershed Agencies, taken from the French water management model, passing regulatory responsibility from the Federation to a regional level. These Agencies were conceived as lawfully autonomous technical, administrative and legal units, assigned to the General Director of CONAGUA, and with faculties are to regulate, know and agree on regional water policy at watershed level in consistency with the National Water Policy.

Watershed agencies introduced an additional element to the institutional political and administrative structure. Before the 2004 amendments, CONAGUA included 13 administrative hydrological regions that contained the 37 natural hydrological regions in the country. As from the nineties, these regional institutions were strengthened when CONAGUA closed some of its states level offices and transferred several functions related to potable water matters to state and municipal governments, while strengthening administration at the regional level (Torregrosa et al., 2010).

18.4 Institutional Framework at State Level

With respect to changes at state level, these have created the institutions that will be in charge of water management at this level, such as the State Water Commissions, Water Institutes, and the creation of state water laws, although these transformations have not occurred simultaneously in all the states in the national territory. Important changes have also taken place at the municipal level and are oriented to reinforce water management institutions such as water utilities as entities decentralized from the municipality or the state governments.

This two-level institutional transformation in water management in the county intends to decentralize water administration without losing control of the process, as it strengthens the state government by transferring functions and resources to it on the one hand, while on the other it promotes the creation of institutions at a regional level for the purpose of regulating and supervising comprehensive water management at the watershed level beyond state government. This double process has created tension between state governments and CONAGUA regional agencies that were not solved until recently. The core point of this tension has to do with the increasing tendency towards state strength and autonomy which thus demand more faculties and functions in water management to be able to solve their problems. It is also manifest in the difficulties of CONAGUA's Watershed Agencies to respond efficiently to the problems and demands of state governments that have arisen as a consequence of the recent institutional changes in addition to financial issues and the lack of specialized personnel. Water, more than ever, has become a crucial factor in the shaping and consolidation of territories of power for the control of the resource. (Torregrosa et al.,2010).

18.5 Water Governance and Integrated Management

The governance and integrated management of water is a complicated task in Mexico due to the huge political, economic and cultural differences and inequities that prevail in its population. From this perspective, the Integrated Water Resources Management model (IWRM) should be seen as an end point and not as a starting point, as a management model with these characteristics implies the preexistence of citizens that exercise their rights and obligations, have equal access to opportunities and resources, and live within a culture of democracy, all of which are far from reality in this country. It would be convenient to conceive the IWRM model as being built "from the bottom up" and not exclusively "from top to bottom" as it's frequently is. In other words, there is the need to recuperate the large range of water management experience in the country at a variety of levels such as micro-watershed, localities and communities, where the population has taken the solution to water access in their hands and involved local authorities to solve problems together. It would be important to have public policies that could encourage and generalize these experiences throughout the country (Torregrosa et al., 2010).

The Mexican State has ceded core areas of public space, not to society in general, but to private interests. This can be observed in the fact that the institutional design that has intended to introduce schemes for participation and the IWRM model, both nationally and locally, has limited not only social participation but also the scope of decentralization within decision making. In addition, the possibilities to build conditions that favor the commitment of participants to the drastic actions needed to slow down the water crisis in the country are small. For example, social participation is a core issue in the design of water policy in Mexico according to CONAGUA, but in reality the institution has not been able to achieve results that effectively reduce water demand. The Watershed Councils, COTAS, Watershed Committees and Commissions, the Management or Advisory Councils for Water and Sewerage services not represent users who do not participate and they lack the sufficient connections with those users and then they are not effective instruments for accountability. Indeed, they have not been able to counterweigh the powerful participants with great influence in decision-making that tend to capitalize the benefits. These "representative" organs have been unable to become an interphase between the State and society that would allow fair, useful and binding exchanges between both spheres, and in which commitments could be achieved with effective actions resulting in the reduction of water extraction and contaminating emissions.

In conclusion, Mexico continues to face problems related to centralization, limited social participation and the selective and unequal distribution of benefits (Torregrosa et al., 2010).

18.6 Registries of Water Rights

The Public Registry of Water Rights (REPDA -Registro Público de los Derechos de Agua) is in charge of water management and control. REPDA includes five groups of users: agriculture, public supply, self-supplied industry and thermoelectric plants, all of which are considered consumptive uses and finally hydro-power, a non-consumptive use.

Table 17 shows the volumes granted under concession in 2008 for the four consumptive uses. Unfortunately the registry is poorly updated, particularly regarding groundwater. In Laguna Seca for example, agriculture has improved accuracy with respect to the number of existing wells (legal, irregular and clandestine) and the total surface irrigated by various technologies (gravity and pressurized), thus COTAS had registered 1,123 wells while REPDA only 656; in other words, REPDA had a sub-registry of more than 40%. Likewise, recovery of water rights from pre-Hispanic and colonial times as well as from agrarian reform is poor.

19. Legal Framework

19.1 Main Regulations

The set of legal regulations and institutions created in Mexico to regulate and manage water form a complex (and confusing) framework of laws and powers which tend to become a labyrinth, even for the experts (Gutiérrez and Emanuelli, 2010)
We can find regulations of interest both in the constitution and in international treaties, as well as federal, state and municipal norms, as can be observed in a much summarized way in Table 18.

The National Water Commission has also issued twelve NOMs related to water which establish the criteria to be observed by agencies operating systems for drinking water, sanitation and sewerage. Of these twelve, six are related to the rural environment:

- NOM-001-CNA-1995. Sanitary sewerage systems. Specifications for water tightness
- NOM-002-CNA-1995. Home outlet for drinking water supply. Specifications and testing methods.

Table 17. Consumptive Uses, According to Extraction source, 2008 (Billions of Millions m³, Km³)

Use	Origen		Total Volume	Percentage extraction
	Surface	Groundwater		
Agriculture [a]	40.7	20.5	61.2	76.8
Public Supply [b]	4.2	7	11.2	14
Self-supplied industry [c]	1.6	1.6	3.3	4.1
Hydro-power plants [d]	3.6	0.4	4.1	5.1
Total	50.1	29.5	79.8	100

NOTE: 1 km^3 = 1 000 hm^3 = 1 billion m^3. Data corresponds to volumes allocated on December 31st, 2007.
[a] Includes agricultural, livestock, aquaculture, multiple and other headings of the REPDA classification, as well as volumes of water still pending registration (2.05 km^3).
[b] Includes public urban and domestic headings of the REPDA classification.
[c] Includes industrial, agro-industrial, service and trade headings of the REPDA classification.
[d] Includes all energy generation plants that are not hydropower plants.
Source: CONAGUA. Deputy Director General's Office for Water Management.

Table 18 Main Legal Regulations Relating to Water, with Information from Rodriguez and Emanuelli, 2010

The Constitution	
Most relevant articles	1st, 3rd, 4th, 5th and 6th° sections of article 27; article 73, section XVII, and article 115, section III, paragraph a
Article 27	Sets down the system for the ownership of water in Mexico and states that water is of public domain as an unalienable and non-lapsable good, although its domain may be transferred to individuals by means of concessions.
Article 73	Determines the authorities who shall regulate the exploitation and use of water, as well as the preservation of its quantity and quality. In addition it gives the House of Representatives the faculty to issue laws on the use of water under federal jurisdiction. It also establishes that the federal executive can promote actions with state and municipal governments, without affecting its powers in the matter of and related to the sphere of their attributions for water management.
Article 115	A reform issued on February 5, 1983, transfers the obligation of the federal government to provide services for drinking water, sewage, treatment and disposal of residual waters to municipalities.

National Water Law (LAN - Ley de Aguas Nacionales)

This is the most important law regarding continental water in Mexico and it regulates the exploitation and use of water, as well as its distribution and control. Its was preceded mainly by the following laws: Federal Irrigation Law of 1926; Law of Water of National Ownership of 1934; Irrigation Law of 1946; the Regulatory Law of Paragraph 5, Article 27 of the Constitution regarding groundwater of 1956 and the Federal Water Law of 1972. It was published in the Federation's Official Journal (DOF - Diario Oficial de la Federación) on December 1, 1992 and was the object of a broad reform in 2004 which modified 114 of its articles and added 66 more, and also transformed several of its articles and chapters.

General Law for Ecological Balance and Environmental Protection

In Article 119-Bis, it states: "In the matter of control and prevention of water pollution, it is responsibility of the state and municipal governments in themselves or through their public agencies that manage water…" to comply with the corresponding NOM (Official Mexican Norm), " as well as require those who discharge into these systems and do not comply with these norms, to set up systems for treatment". Also, it is within their powers "to determine tariffs for the corresponding rights so the respective municipal or state authority may perform the necessary treatment and, if needed, to impose the corresponding sanctions".

State Laws

Although water management in Mexico is governed by a highly centralized scheme, each individual state has the responsibility to regulate the use and vigilance of waters under their jurisdiction, i.e. those located within their territories and not considered national property according to Article 27, Section 5 of the constitution. In addition, while Article 115 of the constitution has granted municipalities the capacity to provide public water and sanitation services, the state legislative also has the obligation to develop the corresponding regulations. Likewise, state authorities must carry out functions conferred to them by CONAGUA, according to LAN. In recent years the following operative programs have been transferred to states: "Efficient Use of Water and Electricity", "Full Use of Hydro-agricultural Infrastructure", "Rehabilitation and Modeling of Irrigation Districts", "Drinking Water and Sanitation in Rural Areas", and "Drinking Water, Sewerage and Sanitation in Urban Areas", among others. Thus, most states have created their own State Water Commissions to comply with the responsibilities they have been acquiring.

Official Mexican Norms Regarding Water

These regulate concrete situations regarding water, and greatly determine how the resource is managed in relation to its availability, quality and access.

NOM-001-ECOL-1996 Establishes the maximum permissible limits of pollutants in wastewater discharges in national waters and goods	Published on January 6, 1997 in the Official Journal of the Federation. The Ministry of the Environment and Natural Resources SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales), through CONAGUA, and the Ministry of Naval Affairs supervises compliance with this NOM, within the scope of its respective competence. This norm establishes that violations shall be sanctioned according to the National Water Law and its regulations, as well as according to the General Law on Ecological Balance and Environmental Protection (LGEEPA -Ley General del Equilibrio Ecológico y la Protección al Ambiente) and the Federal Metrology and Standardization Law (LFMN -Ley Federal sobre Metrología y Normalización) and other applicable legal regulations.

NOM-002-ECOL-1996, which establishes the maximum permissible limits for pollutants in wastewater discharges into urban and municipal sewerage systems.	Published on June 3, 1998 in the Official Journal of the Federation. Supervision of the observance of this NOM corresponds to "state, municipal and Federal District governments within the scope of their respective competence, while their personnel shall verify, inspect and watch over these services when necessary". Violations shall be sanctioned according to the General Law on Ecological Balance and Environmental Protection (LGEEPA -Ley General del Equilibrio Ecológico y la Protección al Ambiente) and other applicable legal regulations.
NOM-003-ECOL-1997, which establishes the maximum permissible limits of pollutants for treated wastewater reused in services to the public.	Published on September 21, 1998 in the Official Journal of the Federation. The object of this norm is to protect the environment and health of the population, and is compulsory for those public entities responsible for the treatment and reuse of water, whether state, municipal and Federal District governments, "in themselves or through their public agencies" or in the cases in which services to the public are performed by third parties. Supervision of this Norm corresponds to SEMARNAT, through CONAGUA and the Ministry of Health, according to their respective powers. Violations to this norm shall be sanctioned according to the General Law on Ecological Balance and Environmental Protection (LGEEPA -Ley General del Equilibrio Ecológico y la Protección al Ambiente), the General Health Law and other applicable legal regulations.
lNOM-127-SSA1-1994, establishes the permissible limits of water quality and the purification treatments for human use and consumption that public and private water supply systems or any moral or physical person who distributes water in the country must comply with.	Published on January 19, 1994 in the Official Journal of the Federation. This norm corresponds to the health sector. This NOM is compulsory for all agencies operating public and private supply systems, or any moral or physical person who distributes water for human use and consumption in the entire national territory. The norm emphasizes that "the adequate quality of water supplied for human use and consumption is fundamental to avoid and prevent disease transmission" of any kind. Thus it establishes the permissible limits to guarantee and preserve the quality of water until its delivery to consumers. The Ministry of Health, together with state governments supervise compliance of this regulation in coordination with the National Water Commission (CNA), each within its respective areas of competence.

- NOM-003-CNA-1996. Requirements during the construction of water-withdrawal wells to prevent the pollution of aquifers.
- NOM-004-CNA-1996. Requirements for the protection of aquifers during the maintenance and rehabilitation of water-withdrawal wells and for the closing of wells in general.
- NOM-011-CNA-2000. Conservation of water resources. Established specifications and methods used to determine average annual availability of national waters.
- NOM-013-CNA-2000. Drinking water distribution networks. Specifications for water tightness and testing methods.

19.1.1 Development of the Regulatory Framework to Control Water Pollution

Municipal

Ever since 1973, when the Ministry of Hydrologic Resources established the bases for registration and monitoring of residual water discharge, the description and classification of all bodies of water in the nation and the objectives regarding its quality, Mexico has had a regulatory framework to protect the quality of water. Unfortunately, it was not carried out due to lack financial support and political willingness. Since 1982, efforts were made to set up regulations for each type of discharge, similar to those in the United States. In all, 44 regulations were established, although because they were hardly applied, they contributed very little to residual water treatment and pollution control. In 1996, a new legal framework was set up to allow the gradual control of pollution and to set up goals regarding the reuse of treated water or its final disposal. Thanks to these regulations, the quality of treated water has doubled since 1996, contrasting with what had been occurring during the seven previous years (estimate according to data from CONAGUA, 2000 and 2005), and will have a much more significant increase as an important volume of the residual water from Mexico City is treated (Jiménez et al., 2010).

Industrial

Concern for the environment began in Mexico in 1971 when the Federal Act to Prevent and Control Environmental Pollution (LFPCCA -Ley Federal para Prevenir y Controlar la Contaminación Ambiental) was issued. This act was in force until 1982, when the Federal Act for the Protection of the Environment (LFPA - Ley Federal de Protección al Ambiente) was brought into effect and later prolonged until 1988. Thus, in the period from 1971 to 1988 many industries included environmental sections in their organizations, although recurring economic crisis postponed many good intentions with respect to environmental issues and businesses eventually closed down their environmental areas. With the General Act for Ecological Balance and Environmental Protection (LGEEPA -Ley General del Equilibrio Ecológico y la Protección al Ambiente) of 1988 and its 1996 and 2007 reviews, a new “environmental market” was created. Nevertheless, most businesses did not create a special environmental office, rather they opened one within or adjacent to other areas such as security or hygiene (López et al., 2010). Unfortunately, personnel in charge of environmental issues often lack formal training in the area, and consequently Mexican industries repeatedly face problems such as the following (López et al., 2010):

- High fines due to non-fulfillment of special conditions for discharge.
- Problems with water coming from systems for water pretreatment.
- Increased cost of drinking and well water.
- Drinking water scarcity.
- Inefficient use and management of water within industries.
- Operation of inefficient water treatment systems within industries.
- Rudimentary reuse and recycling of water.

On the other hand, the lack of structural and functional capacity on behalf of institutions of the federal, state and municipal government for the vigilance and supervision of industrial systems for the management of tap and residual water has hindered the application of and the compliance with environmental laws and regulations on the part of these industries ever since the publication of LFPCCA in 1971 (López et al., 2010).

19.2 Assessment of the Regulatory Framework

The following are deficiencies in the regulatory framework regarding water (Gutierrez y Emanuelli, 2010):

- Although the fact that bodies of surface water are national property is relatively well established, this is not the case with bodies of groundwater.
- There is no clear relationship between public policies to be applied for the management of water and other aspects such as the management of land or rural development.
- The responsibility of water and sanitation services was transferred to municipalities when the level of service coverage was very low, and thus they were required to provide a volume of resources and a complex institutional capacity that they lacked. Consequently this has lead to an inability to provide these services that continues to exist at present.
- LAN is an instrument with a questionable legislative technique as it relates the various entities that manage water resources and their uses in a complex way. This makes is very difficult for citizens to understand the main law and thus opens it wide to discretional administration practices and even corruption. In addition, to the present date the executive regulations corresponding to the 2004 amendments have not been published, deterring understanding with regards to how it is operating in reality and who or how decisions are being made on the matter.
- Deficient vigilance and compliance with NOMs.
- There is no clarity with respect to the specific competent authorities in charge of providing follow up to the application of norms (LFMN, LAN, LGEEPA, General Health Act, etc.), or when or how the surveillance processes for their observance will be achieved when turning to other applicable regulations on the subject.

19.3 The Human Right to Water

It is important to point out that although in the current constitution there is no article explicitly recognizing the human right to water, there are elements that allow it to be recognized implicitly.

Firstly, because the right to water is closely related to the rights recognized in the constitution, such as the right to health, a home or to the environment (established in article 4), that would be impossible without the right to water. Secondly, because several articles in the constitution (2,4 and 27) establish obligations for the authorities in regards to the minimum essential content of this right (at least in the case of indigenous peoples and children).

Also because the right to water has been recognized in a variety of international documents signed by the Federal Executive and ratified by the Senate (Gutierrez y Emanuelli, 2010), such as many International Treatise on the human right to water such as the following (Gutierrez y Emanuelli, 2010) :

- The Convention on the Elimination of All Forms of Discrimination Against Women[7] in 1979.
- The Convention for the Rights of the Child[8] in 1989.
- The International Covenant for Economic, Social and Cultural Rights (ICESCR)[9] in 2002.
- The United Nation's Resolution on the Human Right to Water and Sanitation.

20. References

1. Aboites L.; Cifuentes E.; Jiménez B.; Torregrosa, M. L. (2008), Agenda Nacional del Agua, Academia Mexicana de Ciencias, México, D. F., 66 pp.
2. Aboites L. 2009 La decadencia del agua de la nación. Estudio sobre desigualdad social y cambio político en México. Segunda mitad del siglo XX, México, El Colegio de México.
3. Aboites Aguilar L., Birrichaga Gardida D., Garay Trejo J. (2010) "EL MANEJO DE LAS AGUAS MEXICANAS EN EL SIGLO XX", CAP 2 EN "LOS RETOS DEL AGUA" CAP 3 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO. PP. 21-50
4. Arganis Juárez M., Domínguez Mora R., Jiménez Espinosa M., y Guichard Romero D. 2010 "EVENTOS EXTREMOS" CAP 20 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 51-78
5. Arreguin Cortés F., Alcocer Yamanaka V., Marengo Mogollón H., Cervantes Jaimes C., Albornoz Góngora P., Salinas Juárez G. (2010) "LOS RETOS DEL AGUA" CAP 3 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp. MÉXICO PP. 51-78
6. Caldera A.R, Torregrosa y Armentia M.L. (2010) "PROCESO POLÍTICO E IDEAS EN TORNO A LA NATURALEZA DEL AGUA: UN DEBATE" CAP 12. EN

7 Convention ratified by Mexico 18 December, 1980 by decree published in the Official Journal of the Federation 9 January, 1981. Entailment starting 23 March, 1981. In http://www.hchr.org.mx/documentos/CEDAW%20Final.pdf

8 Convention ratified by Mexico 19 June, 1990 by decree published in the Official Journal of the Federation 31 July, 1990. Entailment starting 21 September, 1990. In http://www2.ohchr.org/spanish/law/crc.htmt

9 Ratified by the Senate 18 December, 1980 and entailment starting 23 March, 1981. In http://daccess-dds-ny.un.org/doc/UNDOC/GEN/G03/402/32/PDF/G0340232.pdf?OpenElement

El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP 317-346.
7. Castelan, E. (2000). "Análisis y Perspectiva del Recurso Hídrico en México". Centro del Tercer Mundo para el Manejo del Agua, A. C. México. Disponible en http://www.agua.org.mx/images/stories/BibliotecaT/docs/INFORMACION_GENERAL_DE_AGUA/analisis_perspectiva_recurso%20hidrico.pdf
8. CFE, Comisión Federal de Electricidad (2009). "Tarifas eléctricas. México." Sitio de Internet: http://www.cfe.gob.mx
9. Comisión Federal para la Prevención de Riesgos Sanitarios, COFEPRIS. Recuperado de http://201.147.97.103/wb/fp/cfp_calidad_bacteriologica/_rid/321?page=4 Consultado el 5 de octubre de 2009.
10. Comisión Internacional de Límites y Aguas (CILA). (2000). Ejemplo de Cooperación entre dos Países. Documento interno. Ciudad Juárez, Chih.
11. Colom, Elisa (2009). "Política de Aguas Internacionales de Guatemala", ponencia en I Encuentro de la Iniciativa Mesoamericana para la Paz y el Desarrollo en Cuencas Compartidas, Universidad del Zamorano Honduras/IDRC-Canadá, La Antigua Guatemala 18-20 de noviembre de 2009.
12. CONAGUA 2003 La participación privada en la prestación de los servicios de agua y saneamiento. Conceptos básicos y experiencias. 2ª. Versión actualizada. México, D. F.
13. CONAGUA 2005 Situación del Subsector de Agua Potable, Alcantarillado y Saneamiento, Edición 2005. México, D. F., Subdirección General de Infraestructura Hidráulica Urbana.
14. CONAGUA, 2007 Estadísticas del Agua en México. Comisión Nacional del Agua. México.
15. CONAGUA (2008). Estadísticas del Agua en México. Comisión Nacional del Agua. México.
16. CONAGUA, 2009 Estadísticas del Agua en México, www.cna.gob.mx p. 108.
17. CONAGUA y SEMARNAT, 2009 Programas de agua potable, alcantarillado y saneamiento. www.cna.gob.mx (consultado en septiembre de 2009)
18. CONEVAL (2007). Los mapas de Pobreza en México: Anexo técnico metodológico, CONEVAL, Ciudad de México.
19. Davila-Poblete, Sonia. Mexico´s Two Principal Hydro-Agricultural Policies from a Gender Perspective. In: Merrey, D. and S. Baviskar (Eds.). Gender Analysis and Reform of Irrigation Management: Concepts, Cases, and Gaps in Knowledge. Proceedings of the workshop on Gender and Water, 15-19 September 1997. Colombo, IWMI: Sri Lanka, 1998.
20. Dávila-Poblete, Sonia. Women and Agenda 21 in Mexico. In Cecilia Tortajada (Ed.). Women and Water Managemet: The Latin American Experience. Oxford University Press, New Delhi, 2000.
21. Instituto Nacional de Estadística,

Geografía e Informática. Conteo General de Población y Vivienda 2005.
22. Guevara Sanginés A., Soto Montes de Oca G., Lara Pulido J. 2010 "POBREZA" CAP 15 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 411-454
23. Gutiérrez Rivas R. y Emanuelli Panico S. 2010 "RÉGIMEN JURÍDICO DEL AGUA CONTINENTAL EN MÉXICO: UN ANÁLISIS CRÍTICO" CAP 23 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 647-680
24. INEGI (2005). II Conteo de Población y vivienda 2005, Instituto Nacional de Estadística y Geografía. México.
25. Jiménez, B.; Marín, L. (eds.); D. Morán, O. Escolero y J. Alcocer (coord.) (2005). El agua en México vista desde la Academia. Academia Mexicana de Ciencias. México, D.F.
26. Jiménez Cisneros, B. E. (2006). Agua e industria en Latinoamérica y el Caribe. En La gota de la vida: hacia una gestión sustentable y democrática del agua. Fundación Helnrich Böll.
27. Jiménez E., M. y Eslava M., H. (2008). "Mapas de riesgo nacional a escala municipal", memorias del XVII Congreso Mexicano de Meteorología, Monterrey, Nuevo León, México.
28. Jiménez Cisneros B., Durán Álvarez J.C. y Méndez Contreras J.M. (2010) "CALIDAD"" CAP 10. EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 265-290
29. Kauffer Michel E., García García A., Solís Hernández G. (2010) "EL AGUA EN LA FRONTERA SUR DE MÉXICO: ENTRE CONTINUIDADES Y CLAROSCUROS" cap 18 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 505-528
30. López Zavala M.A., y Flores Arriaga B. (2010) "INDUSTRIA" CAP 7 EN "EL MANEJO DE LAS AGUAS MEXICANAS EN EL SIGLO XX", CAP 2 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 179-202
31. Martínez Austria P., Patiño Gómez C., Montero Martínez M., Pérez López J.L., Ojeda Bustamante W., Mundo Molina M., y Hernández Barrios L. (2010) "EFECTOS DEL CAMBIO CLIMÁTICO EN LOS RECURSOS HÍDRICOS" cap 19 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 529-562
32. Mazari Hiriart M., Espinosa García C., López Vidal Y., Arredondo Hernández R., Díaz Torres E., Equihua Zamora C. (2010) "VISIÓN INTEGRAL SOBRE EL AGUA Y LA SALUD" CAP 11 "EN EL MANEJO DE LAS AGUAS MEXICANAS EN EL SIGLO XX", CAP 2 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702

pp., MÉXICO PP. 291-316

33. Moreno Vázquez, J., Marañón Pimentel B., López Córdova D., 2010 "LOS ACUÍFEROS SOBREEXPLOTADOS: ORIGEN, CRISIS Y GESTIÓN SOCIAL". CAP. 4 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 79-116
34. Montesillo Cedillo J.L., Fonseca Ortiz C. 2010 "AGUA, DESARROLLO ECONÓMICO Y DESARROLLO HUMANO" CAP 13 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 347-382
35. Nazar BeutelspacherA., Zapata Martelo E., Ramírez Castel V. 2010 "GÉNERO Y AGUA. ESTRATEGIAS PARA ALCANZAR LA SUSTENTABILIDAD CON EQUIDAD" cap 14 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 383-410
36. Palerm Viqueira J., Collado Moctezuma J., Rodríguez Haros B. (2010) "RETOS PARA LA ADMINISTRACIÓN Y GESTIÓN DEL AGUA DE RIEGO" cap 6 EN EL AGUA EN MÉXICO: CAUCES Y ENCAUCES, JIMENEZ B., ABOITES L., Y TORREGROSA M.L. ED. ACADEMIA MEXICANA DE CIENCIAS, MÉXICO. PP. 141-178
37. Palerm, J. y T. Martínez (Eds.), Aventuras con el Agua. La Administración del Agua de Riego: Historia y Teoría, Colegio de Postgraduados, 2009.
38. Pemex (2002 a 2009). Informes de Desarrollo Sustentable. Anexo estadístico. Disponibles en http://desarrollosustentable.pemex.com/portal/index.cfm
39. Peña de la Paz, J.F., E. Herrera Pinedo, L.E. Granados, (2010). "PUEBLOS INÍGENAS, AGUA LOCAL Y CONFLICTO" CAP. 16 EN El Agua en México: Cauces y encauces. Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO. 455-478 PP.
40. Pineda Pablos, Nicolás (2002). "La política urbana de agua potable en México: del centralismo y los subsidios a la municipalización, la autosuficiencia y la privatización". Región y Sociedad. Revista de El Colegio de Sonora. Vol. 14, núm. 24 (mayo-agosto), pp. 41-69
41. Pineda Pablos N., (2008). Nacidos para perder dinero y derrochar agua. El inadecuado marco institucional de los organismos operadores de agua en México. En La Gestión de los recursos hídricos: realidades y perspectivas. Tomo 1, editado por Denise Soares, Sergio Vargas y María Rosa Nuño. Jiutepec, Morelos: Instituto Mexicano de Tecnología del Agua; Guadalajara, Jalisco: Universidad de Guadalajara, pp. 121-150
42. Pineda Pablos N., Salazar Adams, A., Buenfil Rodríguez M. (2010) "PARA DAR DE BEBER A LAS CIUDADES MEXICANAS: EL RETO DE LA GESTIÓN EFICIENTE DEL AGUA ANTE EL CRECIMIENTO URBANO" cap 5 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites

A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 117-140

43. Román Calleros J., Cortez Lara A., Soto Ortiz R., Escoboza García F., Viramontes Olivas O. (2010) "EL AGUA EN EL NOROESTE" CAP 17 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 479-504
44. Ruelas Monjardín C., Chávez Cortes M., Barradas Miranda V., Octaviano Zamora V., García Calva L. (2010). "USO ECOLÓGICO" CAP 9 "EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 237-264
45. Sandoval Minero R. (2010) "LA EVOLUCIÓN DEL MARCO INSTITUCIONAL DEL AGUA POTABLE Y EL SANEAMIENTO URBANOS EN MÉXICO: UN ANÁLISIS COGNITIVO PRELIMINAR" CAP 22 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 625-646
46. SEMARNAT (2003). Norma Oficial Mexicana que establece las especificaciones ambientales para el manejo de agua congénita asociada a hidrocarburos, que establece los límites máximos permisibles de diversos contaminantes para la descarga de agua congénita, así como las características que deben tener los pozos, para la reinyección de la misma.
47. SEMARNAT (2008). Estadísticas del Agua en México, Edición 2008, SEMARNAT, Ciudad de México.
48. Sheinbaum Pardo C., Chávez Baeza C. y Ruíz Mendoza J. (2010) "PRODUCCIÓN DE ENERGÍA" CAP 8 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 203-236
49. Soto Montes de Oca, G. (2007). Agua: Tarifas, escasez y sustentabilidad en las megaciudades. ¿Cuánto están dispuestos a pagar los habitantes de la Ciudad de México? Sistema de Aguas de la Ciudad de México, Universidad Iberoamericana, Centro de Estudios Jurídicos y Ambientales y Procuraduría Ambiental y del Ordenamiento Territorial del D.F., México.
50. Torregrosa M.L., Paré Ouellet L., Kloster Favini K., Vera Cartas J. (2010) "ADMINISTRACIÓN DEL AGUA" CAP 21 EN El Agua en México: Cauces y encauces Jiménez, B., Torregrosa M.L. y Aboites A. Editores, Academia Mexicana de Ciencias, 702 pp., MÉXICO PP. 595-624
51. UNICEF (2006). Progreso para la Infancia: Un balance sobre agua y saneamiento, UNICEF, Nueva York.
52. World Economic Forum (2009). Energy vision, update 2009. Thirsty Energy: Water and energy in the 21th century. World Economic Forum in partnership with Cambridge Energy Research Associates. Disponible en http://www2.cera.com/docs/WEF_Fall2008_CERA.pdf

Undeveloped Beach Sallie Peachie, Corn Island Nicaragua

Water Resources in Nicaragua

A Strategic Overview

Editor
Katherine Vammen[1]

Author
Iris Hurtado[1], Francisco Picado[1], Yelba Flores[1], Heyddy Calderón[1], Valeria Delgado[1], Selvia Flores[1], Yader Caballero[1], Mario Jiménez [1,2], Rosario Sáenz[3].

[1]Centro para la Investigación en Recursos Acuáticos de la Universidad Nacional Autónoma de Nicaragua

[2]Facultad de Medicina de la UNAN Managua

[3]Fundación Nicaragüense de Desarrollo Sostenible

Table 1. Water Availability per Capita

Country	Water availability per capita m^3/cap.	
Guatemala	12,121	
Honduras	15,211	
Belize	64,817	
Nicaragua	38,668	
El Salvador	2,876	
Costa Rica	31,318	
Panamá	52,437	
Central America	31,064	
Brazil	32,256	= C.A.
United States	8,906	29 % C.A.
Great britain	2,471	8 % C.A
Switzerland	7,427	24 % C.A.
South Africa	1,187	4 % C.A.
Holland	5,758	18 % C.A.
Mexico	4,742	15 % C.A.

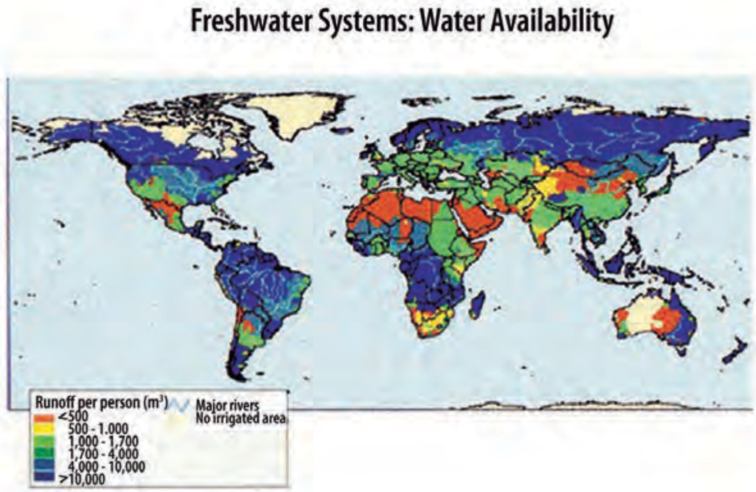
Source: World Bank, 2001.

1. Introduction

Nicaragua is a particularly privileged country with respect to water resources. The amount of water available per capita is 38, 668 cubic meters per year (m^3/capita/year), i.e. greater than the average for Central America.

It is worth noting that its water availability is approximately four times greater than that of the United States or certain European countries such as Switzerland (Table I.1).

When compared to the rest of the world, water availability in Nicaragua expressed as run-off per capita (m^3) reaches levels of >10,000 (FIG.1). According to the Environmental Performance Index (Yale Center for Environmental Law & Policy, 2010) Nicaragua is considered to have the optimum level for water stress (water scarcity in a territory when considering the volume of water shared by a certain population) with the highest possible score of 100 points, meaning 0% of the population living under water stress. It also has a score of 100 points for water scarcity



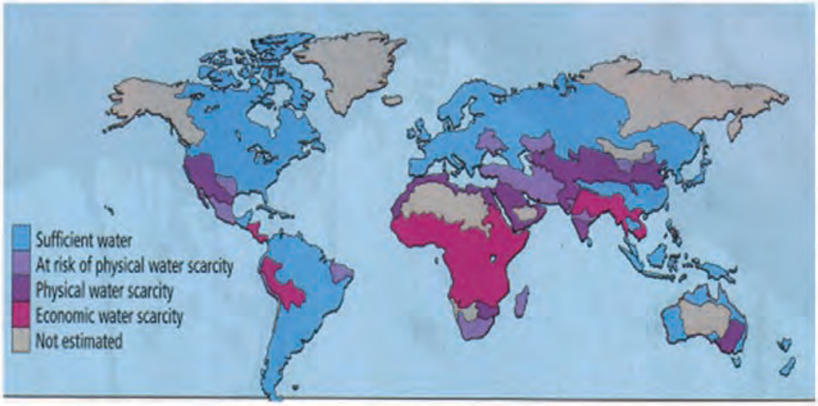
SOURCE: FEKETE ET AL., GLOBAL, COMPOSITE RUNOFF FIELDS.

FIG. 1. Epicontinental Water Throughout the World: Availability Expressed as Run-off Per Capita

Nevertheless, 45.8% of the population in the country lives in poverty and 15.1% in extreme poverty. In rural areas, two out of three people are poor, while 27.4% or nearly one third of the rural population lives in extreme poverty (INIDE, 2005). All of Central America is considered to be in economic scarcity of water due to the lack of financial resources to use and maintain the adequate quality of water sources for human consumption, which implies issues regarding good integrated governance of the resource (FIG. 2).

With respect to water quality (information from UNEP/GEMS), the Environmental Performance Indices system mentioned above gives Nicaragua a score of 42.3 points, placing it in 136th place out of 163 countries evaluated. The pollution of Nicaragua's freshwater is the result of population growth in synergy with deficient sanitary infrastructure (for both liquid and solid wastes) and the lack of territorial planning that has produced environmental decline and is reflected in water quality. Problems with pollution have continued because land is being used in ways that are contrary to its potential uses, in other words deforestation and land conversion into grassland for cattle and other agricultural uses. Poor water quality provokes problems directly affecting the quality of life and the health of human populations (Section 7).

Nicaragua's favorable water availability situation is essential as the starting point for the improvement of water quality and human health, along with the promotion of economic development. The generation of information and a better understanding of the physical, natural and economic conditions of water resources, together with the establishment of the institutional and legal conditions for good water management are vital to promote the country's development. Likewise, an information system on water resources is a basic instrument for its improved governance.



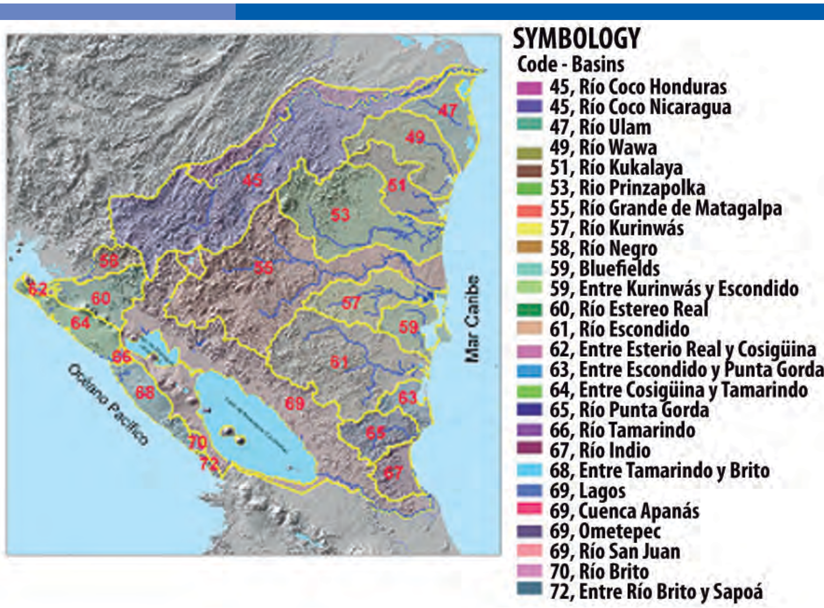
SOURCE: INTERNATIONAL WATER MANAGEMENT INSTITUTE, 2007.

FIG. 2 . Economic Scarcity of Water

The aim of this article is to provide the existing information on the current state of hydric resources taking into consideration the factors that have an influence on their uses, and to offer a strategic overview for the purpose of developing plans and policies to protect and improve the use and sustainability of water.

2. Hydric Resources in Nicaragua

From a hydrographic viewpoint, Nicaragua is divided in 21 basins distributed in two great watersheds: the Pacific Watershed (12,183.57 km^2) and the Caribbean Watershed (117,420.3km^2) (Table 2). FIG. 3 is a map of Nicaraguan basins.



SOURCE: PRODUCED BY CIRA/UNAN FROM INETER DEMARCATION.

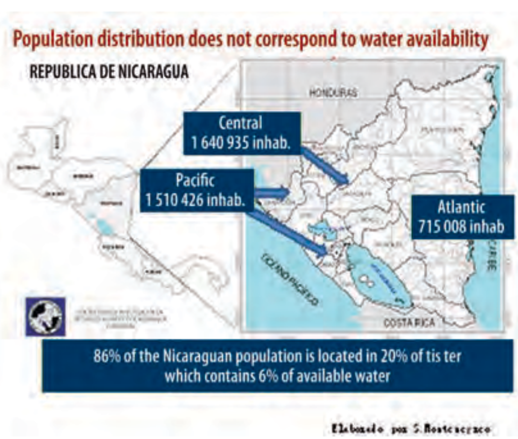
FIG. 3 . Map of Nicaraguan Basins.

Table 2 . Areas and Precipitation per Basin and Watershed

Caribbean Watershed			
Basin	**Name of Basin**	**Area**	**Precipitation**
No	**Main River**	**km²**	**Annual Average (mm)**
45	Coco River	19,969.00	1, 927
47	Ulang river	3 777.40	2 405
49	Wawa River	5 ,371.98	2, 820
51	Kukalaya River	3, 910.25	2, 800
53	Prinzapolca River	11, 292.40	2, 586
55	Grande de Matagalpa	18, 445.00	2, 095
57	Kurinwas	4, 456.76	2,725
59	Between Kurinwas River and Escondido River	2, 034.20	3, 564
61	Escondido River	11, 650.00	2, 722
63	Between Escondido River and Punta Gordariver	1, 592.96	3,710
65	Punta Gorda River	2, 867.42	3, 552
67	Between Punta Gorda River and San Juan River	2, 228.86	4, 510
69	San Juan en Nicaragua River	29,824.00	1,694
	TOTAL	117,420.23	
Pacific Watershed			
Basin	**Name of Basin**	**Area**	**Precipitation**
No	**Main River**	**km²**	**Annual Average (mm)**
58	Negro River	1 ,428.00	1, 859
60	Estero Real River	3, 690.60	1, 682
62	Between Estero Real River and Volcán Cosiguina	429.00	1 ,881
64	Between Volcán Cosiguina and Tamarindo River	2, 950.66	1, 670
66	Tamarindo River	317.62	1, 175
68	Between Tamarindo River and Brito River	2, 768.69	1, 357
70	Brito River	274.00	1, 316
72	Between Brito River and Sapoa River	325.00	1, 625
	TOTAL	12, 183.57	

Source: INETER.

Fifty one rivers drain into the Atlantic, four into Lake Xolotlán (also called Lake Managua) and twelve into Lake Cocibolca (also known as Lake Nicaragua), which in turn drain into the Caribbean Sea through the San Juan river. The Pacific basins are smaller and its rivers are shorter. In addition, the area has the best agricultural land and is where more than 60% of the country's population lives (FIG. 4.).



SOURCE: MONTENEGRO, S., KEYNOTE SPEECH: NICARAGUA, A COUNTRY WITH WATER AND THIRST.

FIG. 4. Population Distribution in Nicaragua

Twelve rivers drain directly into the Pacific Ocean. The country includes two large lakes and 18 lagoons, of which nine are in the Pacific region, five in the Central region and four in the Atlantic. Furthermore, of the four dams in Nicaragua, three are for the production of hydroelectricity and one for irrigation and fish farming. The abundant surface water resources are seasonal and are distributed irregularly; ninety three percent are in the Atlantic region and only 7% in the Pacific (Table 2). There are four main aquifers in the Pacific and 21 in the Atlantic, including the river low plains (INETER).

Of the 19 largest basins in Central America, five are found in Nicaragua, two of which are bi-national. The basin of the San Juan River (Basin N° 69) is the second largest in Central America (Table 3).

Table 3. The 19 Largest Watersheds in Central America

Drainage	Watershed	Country	Area km^2
Atlantic	Usumacinta River	México-Guatemala-Belice	5,1 190.36
Atlantic	San Juan River	Nicaragua-Costa Rica	42,051.61
Atlantic	Patuca River	Honduras	24,593.87
Atlantic	Coco River	Honduras-Nicaragua	24,345.16
Atlantic	Ulua River	Honduras	21,396.03
Atlantic	Motagua River	Guatemala-Honduras	18,056.56
Atlantic	Río Grande de Matagalpa	Nicaragua	17,959.96
Pacific	Lempa River	El Salvador-Guatemala-Honduras	17,882.98
Pacific	Ocosito River	Guatemala	12,944.44
Atlantic	Escondido River	Nicaragua	11,517.81
Atlantic	Belize River	Belize	10,529.36
Atlantic	Agua River	Honduras	10,311.35
Atlantic	Dulce River	Guatemala	8,016.75
Atlantic	Sico, Tinto or Negro River	Honduras	7,714.84
Atlantic	Choluteca River	Honduras	7,430.68
Atlantic	Warunta River	Honduras	6,012.10
Atlantic	Hondo River	Belize	5,948.14
Atlantic	Wawa River	Nicaragua	5,501.60
Pacific	Chucunaque River	Panama	5,043.52

Source: Yelba Flores.

3. Uses of Water

Water extraction strategies have made a priority of groundwater use, representing 70% of the current supply volume of drinking water. Of the total water extracted in 2008, the farming sector consumed the greatest volume (83%), followed by the industrial sector (14%) and finally the domestic sector (3%) (Table 4), and this water consumption pattern is estimated to continue in the coming years. Furthermore, agriculture relies mainly on groundwater sources. These waters are concentrated in the Pacific region within the Departments of León and Chinandega, and the main crops they irrigate are sugarcane, rice, sesame, tobacco and sorghum.

Table 4. Water Use per Sector in 2008

Total water extraction in Nicaragua (mm^3)	Water use per sector (% mm^3)		
	Farming Domestic	Domestic	Industrial
1,794.9	83%	3%	14%

Source: (MAGFOR, 2008; CONAGUA and WWC, 2006)

The estimated total water demand in Nicaragua is 13,462.18 mm^3/year (PHIPDA, 2003).

According to the Empresa Nicaragüense de Acueductos y Alcantarillados –ENACAL (Nicaraguan Company for Aqueducts and Sanitation) (BCN, 2010) (Banco Central de Nicaragua, 2010. Nicaragua en Cifras 2010.), water demand in the 14 years prior to 2008, excluding the Departments of Matagalpa and Jinotega, has followed the performance shown in FIG. 5. It can be observed that Nicaraguan industry is one of the sectors with the lowest water use with a relatively constant demand in contrast to water use by residential sector. (More details can be found in Section 3.2)

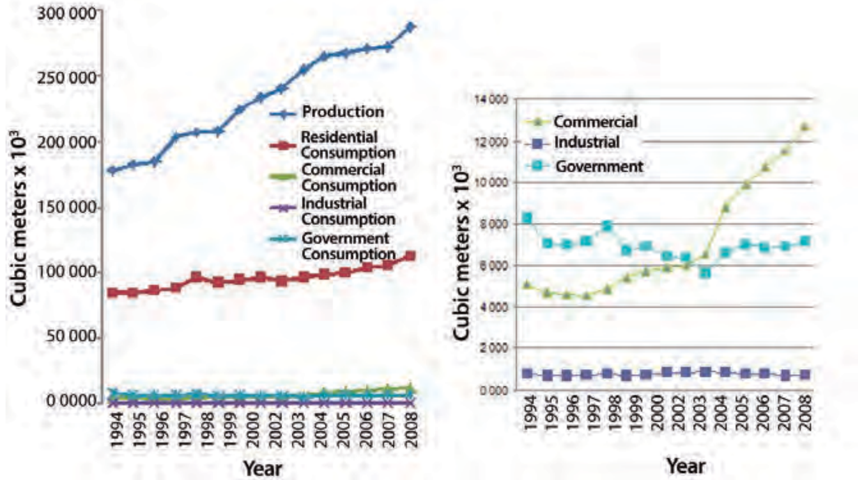
Water demand by the domestic sector has increased annually as a result of the country's high population growth of between 1 and 2% (1.7% annually according to the National Institute for Statistics and Census [INEC - Instituto Nacional de Estadísticas y Censos], 2005, 1.3% annually according to the National Institute for Information on Development [INIDE-Instituto Nacional de Información de Desarrollo], 2008).

In contrast, according to data published by the Banco Central de Nicaragua, from 2008 to 2010 the increase in water demand by the residential sector was nearly 13% (BCN, 2010). Nevertheless, municipal supply has not increased accordingly. Such population growth puts increasing pressure on water sources as national demand will grow year by year, no matter the competition between the aforementioned sectors. Moreover, it has been estimated that 94% of surface water sources are renewable, while 70% of groundwater sources are not (FAO-Aquastat, 2005). (More details in Sections 3.5 and 5.1.)

3.1 Water for Human Consumption: Quantity and Access

3.1.1 Water Availability for Human Consumption

Although Nicaragua has abundant surface and groundwater sources that allow its current demand to be satisfied, these sources have an important seasonal component. Consequently, there is variation in the estimated data published on the national availability of water.



SOURCE: BANCO CENTRAL DE NICARAGUA YEAR BOOK 2001 - 2008. INFORMATION DOES NOT INCLUDE THE DEPARTAMENTS OF JINOTEGA AND MATAGALPA

FIG. 5. Billed Use and National Production of Water

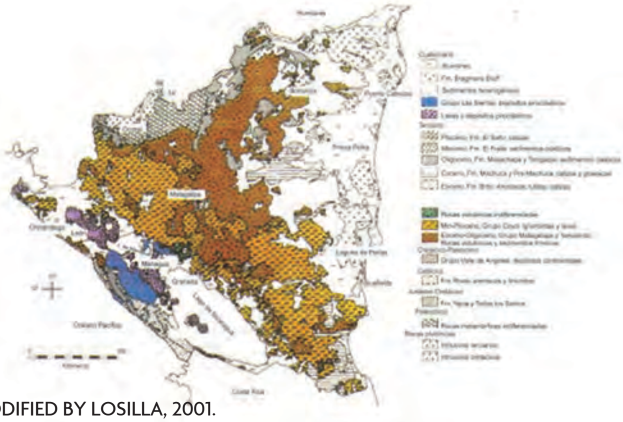
These estimates vary between 137, 448 and 192, 690 Mm^3/year (PANic, 2001–2005; FAO Aquastat, 2005), and only 7% correspond to the country's Pacific watershed. Considering the water availability figure of 192, 690 Mm3/year and that the Nicaraguan population for 2010 is 5, 995, 928 inhabitants (https://cia.gov/library/publications/the-world-factbook/), the amount of water per capita would be 32.14 x 1000 m^3.

In spite of the great volume of surface waters available in the country, the main water supply source is groundwater because surface waters are more polluted. Groundwater is found within quaternary alluvial aquifers co-existing with tertiary pyroclastic sands and quaternary volcanic deposits in fractures in the Nicaragua Depressions and the Pacific and Caribbean Plains. The main aquifers are found in the Pacific region as geological formations favors the presence of groundwater (FIG. 6.). As mentioned above, agriculture mainly relies on groundwater in this part of the country. In contrast, the Atlantic area -also called the Atlantic Coast- apart from being the largest (46 600 km^2), has a greater availability of surface water resources, while the Central area has an intermediate nature with some rivers with a constant flow and productive valleys of groundwater.

Lake Colcibolca has the greatest surface water potential for consumption with an area of 8,264 km^2, and an average discharge volume to the San Juan River of 12,614.4 mm^3/year. Law 620 of the Ley General de Aguas Nacionales (General Water Law), has declared the lake as a natural reserve destined for human use and irrigation in the future (La Gaceta, 2007b).

3.1.2 Availability of Surface Water

The surface water available in Nicaragua is approximately 309,284 mm^3/year (IEA-MARENA, 2001). Nearly 44% of this water makes up the national surface runoff. However, this information is only an approximation of the real values as hydrometric information

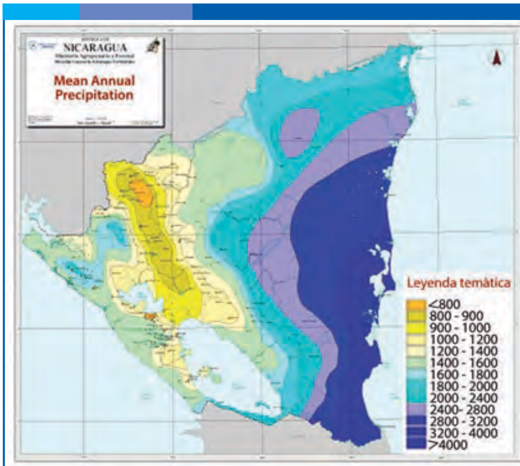


SOURCE: WEYL, 1980, MODIFIED BY LOSILLA, 2001.

FIG. 6. Geological Map.

does not cover all hydrographic basins. Of the 21 existing basins, eight drain into the Pacific Ocean, while the rest drain into the Caribbean Sea. The Pacific basins cover nearly 10% of the national territory in which precipitation varies from 500 mm to 1000 mm throughout the year, while in contrast, precipitation along the Caribbean watershed, reaches values of up to 4000 mm per year. FIG. 7 illustrates the distribution of precipitation. The areas with less precipitation are the most vulnerable to drought. Among the permanent, intermittent and temporary bodies of water in the country, Nicaragua has close to 63 rivers. The greater Nicaraguan lakes are the Cocibolca or Nicaragua, with a surface of 8,133 km^2, and the Xolotlán or Managua, with a surface of 1,016 km^2 (GWP CA, 2006). Of the 21 basins, two are transboundary: a) the basin of the Coco River, extending throughout 24,476 km^2, 21% of which belongs to Honduras, and b) the San Juan River basin with 41,870 km^2, 32% of which are found in territory of Costa Rica.

As mentioned previously, Nicaragua's abundant surface water resources are seasonal and



SOURCE: (MAGFOR, 2002).

FIG. 7. Mean Annual Precipitation

irregularly distributed. Table 5 shows an estimate of the availability of national water resources per region as presented by OPS-OMS.

Table 5. Hydric Resource Availability in the Country.

Region	Surface water (Mm^3)	Groundwater (Mm^3)	Total (Mm^3)
Pacific	4 023	2 862	6 885
Central	18 798	172	18 970
Atlantic	72 192	30	72 222
Total	95 013	3 064	98 077

Mm^3: million cubic meters

Source: (OPS-OMS, 2004)

3.1.3 Groundwater Availability

The main groundwater sources in Nicaragua are concentrated in the Pacific area; they are considered the most important because of their available potential which results from the positive conditions for recharge. The main aquifers in the Pacific area, mostly phreatic in character, correspond to reservoirs associated to Pliocene to recent Quaternary volcanic deposits and have an estimated groundwater potential of 2,959 Mm^3/year (GWP CA, 2006). The estimate of groundwater availability for the Central region is 172.3 Mm^3/year (GWP CA, 2006), while in the Atlantic region the OPS-OMS has reported a figure of 30 mm^3/year (OMS, 2004) (Table 5).

The Atlantic aquifers have not been studied in detail, thus the lack of corresponding information. Approximately 90% of the drinking water supply comes from wells. As mentioned, groundwater resources are more abundant in the Pacific as a consequence of a better hydrogeological environment that favors water seepage and storage. The predominating aquifers in the Central region contain reserves in fractured media which supply small communities. Table 6 shows additional data for estimates of availability in certain aquifers in the Pacific and Central regions as reported by the Nicaraguan Institute for Territorial Studies (INETER -Instituto Nicaragüense de Estudios Territoriales).

3.1.4. Access to Hydric Resources

Access to water is presented in term of national supply coverage; however it is important to note that although both surface and groundwater volumes are sufficient, there are serious deficiencies with respect to residential access. In spite of Nicaragua's great hydric potential, with total renewable

Table 6. Availability of Groundwater Resources

Pacific Underground Basins	Estimated Potential (Mm^3/year)	Central Region Groundwater Basins	Estimated Potential (Mm^3/year)
León–Chinandega	462.0	Valle de Jalapa	10.0
Nagarote–La Paz Centro	114.0	Valle de Ocotal	5.0
Tonalá–Río Negro–Estero Real	54.0	Valle de El Jícaro	5.0
Los Brasiles–Chiltepe	4.5	Valle de San Juan de Limay	5.0
Tipitapa–Malacatoya	118.0	Valle de Estelí	5.0
Managua–Granada	75.0	Valle de El Sauce	10.0
Nandaime–Rivas	120.0	Valle de Sébaco	23.0
Meseta de Carazo	75.0		
Valles Costa Pacífico Sur	40.0		
Sinecapa–Río Viejo	114.0		
Punta Huete	40.0		
East Shore Lake Nicaragua	150.0		

From www.ineter.gob.ni (Mm^3: million cubic meters) water resources of approximately 197 km^3/year (FAO-Aquastat, 2005), the current supply does not cover the total demand from domestic, agricultural and industrial sectors. (More details in Sections 5.1 and 5.10, specifically for rural areas).

3.2 Industrial Uses

In the 1990's, 260 large industries existed in Nicaragua, 234 of which were found in the Pacific region. Of these, the most numerous were the food and beverage industries, currently catalogued as the most polluting. Nicaraguan industry is supplied by groundwater, although water consumption by this sector is small compared to that of other sectors (FIG. 5). According to data from the Report on the Environment in Nicaragua (Informe Estado del Ambiente en Nicaragua (IEA-MARENA, 2001), industry and agriculture together extract close to 7.0 Mm^3 of water. Nevertheless, although industry is the sector consuming the least water in Nicaragua, the index for industrial use is greater than the index of international norms (IEA-MARENA, 2001).

Nearly 30% of the Gross Internal Product (GIP) in Nicaragua comes from the industrial sector; for comparison, in countries highly in debt this percentage is 26% (WWAP, 2006). The most important industrial activities are manufacturing, construction and mining. The manufacturing industry consists mainly of food, beverage, tobacco, metalworking, paint, textile, pharmaceutical, dairy and lumber industries, all of which use a considerable amount of water. Nevertheless, because most of the major industries in the country possess their own water sources (ENACAL, 2005) and as a consequence much of the water they use has not been registered nor billed for, complete data on extraction is lacking and therefore the volume they consume appears to be much smaller than that of other sectors (FiG. 4). A part of the industrial sector is supplied by ENACAL (INEC, 2003). Table 7 shows historical data for water use in the industries it supplies. In the year 2008, ENACAL billed for industries for 745.4 Mm^3 (23.64 m^3/s) of water. Industrial use of water in Nicaragua is estimated to be 14% (Table 4) of the total annual water volume extracted (CONAGUA and WWC, 2006). As mentioned above, an exact figure for water consumption is lacking because the water distribution company does not provide all companies.

3.2.1 Characteristics of National Industry

Because Nicaragua's economic development is based on agriculture, its industrial activity has been limited to a few areas. An important number of industrial businesses still operate with obsolete machinery, resulting in high operation costs and high water use, although there are outstanding industries which use modern technology. On the other hand, certain industries, such as food, timber and tannery industries, have promoted the development of local technology (MIFIC, 2006). Approximately 581 manufacturing industries, corresponding to close to 18% of the national total (MARENA, 2001), are concentrated in the city of Managua (INEC, 2003). Most of these industries belong to the food, non-metallic mineral or construction, textile, clothing and chemical (oil refinery, pharmaceutical, soap, paint, etc.) sectors, while 190 are a part of the medium-sized to large industrial corporations of Managua (ENACAL, 2005).

Table 7. Water Production and Billed Supply by the ENACAL Water Distribution Company

Year	Production volume	Billed use (Mm³/year)					
		Residential	Commercial	Industrial	Government	Municipal	Total
1995	182,753.7	85,331.5	4,683.4	711.8	7,041.4	97,056.3	97,768.1
1996	184,760.0	86,665.7	4,631.1	719.9	6,970.0	98,266.8	98,986.7
1997	203,776.5	88,549.3	4,562.8	737.5	7,168.5	100,280.6	101,018.1
1998	207,735.5	95,964.1	4,896.5	776.0	7,864.5	108,725.1	109,501.1
1999	208,172.6	92,623.1	5,437.7	708.5	6,688.6	104,749.4	105,457.9
2000	224,022.8	94,557.5	5,694.7	739.8	6,897.2	107,149.4	107,889.2
2001	233,217.5	96,245.3	5,863.2	846.2	6,425.4	108,533.9	109,380.1
2002	240,499.4	94,239.8	5,958.6	848.8	6,342.5	106,540.9	107,389.7
2003	254,961.8	96,832.0	6,546.0	875.8	5,632.2	109,010.2	109,886.0
2004	264,930.3	98,599.7	8,853.6	838.0	6,600.2	114,053.5	114,891.5
2005	267,609.7	99,852.0	9,865.5	815.2	6,996.0	116,713.5	117,528.7
2006	271,065.5	103,336.7	10,742.2	756.8	6,874.6	120,953.5	121,710.2
2007	272,960.8	105,100.3	11,520.0	692.7	6,894.2	123,514.5	124,207.2
2008	286,974.0	112,519.6	12,701.2	745.4	7 120.0	132,340.8	133,086.2

Source: Non-published data

3.2.2 Water Sources for Industrial Use

In the same way as in other human societies (WWAP, 2006), Nicaraguan industry has been strategically established near sources of clean water (surface and groundwater) not only to be able to exploit it, but also for the spilling of wastewaters.

A large number of industries are concentrated in Managua's industrial park, on the cost of Lake Xolotlán. While mid-sized industries obtain their water supply (ENACAL, 2005) from drilled wells that have not yet been inventoried, the remaining industries are supplied by ENACAL (INEC, 2003). Processing technologies currently used do not allow optimal use of water, so it later becomes part of industrial effluents.

3.2.3 Industrial Use and Consumption of Water

Water has a variety of industrial uses: as a raw material, as a solvent, for transport, heating or cooling, etc. According to data from the World Bank (2201) the volume of water used industrially in Nicaragua in the year 2000 was 30.0 Mm³. However information for billed use reported by ENACAL for that year (Table 7) corresponds only to 2.5% of this amount (Figure 5).

In the year 2000 the industry value added (IVA) and the industrial water productivity, defined as the ratio between the IVA and the annual volume of water extracted by industry from the source, was US$0.48 billion and 14.34 US$/m³, respectively (WWAP, 2006).

For the year 2005, the industry value added was approximately US$0.75 billion. Although this figure is greater than previous years, it is lower than the IVA for the rest of Central America (WWAP, 2006). The low levels of industrial water productivity are reflected in the unrealistic value of the resource and its poor industrial use. This is common in countries where the fees for industrial water uses are low, as the case of Nicaragua. In other Central American countries industrial water productivity ranges from 9 -17 US$/$m^3$. Excluding the departments of Matagalpa and Jinotega, water consumed by industry during the years 2000, 2001 and 2002, was 739,775 m^3, 847, 085 m^3 and 849,236 m^3, respectively; of these, 60% to 65% were used by industries in Managua (INEC, 2003).

During this period, nearly 812,000 m^3 were billed, representing 0.75% of the average total billed consumption of 233 × 10^6 m^3 for the entire system, including industry, government, domestic and commercial use (INEC, 2009). Although FIG. 5 shows that billed-consumption for the industrial sector remained constant from the 1990's to 2008, this does not mean there has not been an increase in water use. To date, the system for "charging fees for the use, exploitation, discharge and protection of hydric resources" as established by Law 620, General Law for National Water of 2007, has yet to exist.

3.3 Agricultural Uses

Agriculture has historically been the country's main economic activity and Nicaragua has one of the highest rates of agricultural land use in Central America (Table 8).

Table 8. Agricultural Land Use in Central America

Country	Agricultural Land Use (% total area)	% of GIP from Agriculture (% 1999)	% Irrigated Land
Guatemala	41,6	23	6,6
Honduras	6,1	19	3,4
Belize	77,4	10	4,4
Nicaragua	32,0	16	3,7
El Salvador	62,3	32	3,2
Costa Rica	55,7	11	25
Panamá	28,6	7	4,9
	43,4	**16,8**	**7,3**

Source: World Bank: Agricultural Land Use; Selected Countries, 2001.

The Central Bank of Nicargua (BCN -Banco Central de Nicaragua) reports in its 2001-2008 yearbook that agriculture, forestry and fishery contributed 19.1% of Nicaragua's GIP in 2008, thus showing the importance of agricultural activities in the country's economy.

From 2000 to 2008, more individuals worked in agricultural and fishery activities, form 27% to 30%, than in any other economic sector (BCN, 2009: based on projections from INIDE, Home Surveys to Measure Employment, 2005). Stockbreeding remained constant in the past decade at between 9% and 10% of the GIP (CONAGAN, 2009).

It is worth noting that the contribution of agriculture to the GIP fell from 20.1% in 2006 to 19.1% in 2008 as a consequence of hurricane Felix which caused considerable losses in the sector. Agricultural activities are closely linked to water availability in Nicaragua. Indigenous peoples practiced subsistence farming and settled on the shores of water sources. In colonial times, the country became part of the global market and started to export agricultural products, a situation which has prevailed unchanged to the present day.

The most fertile land is found in the Pacific Lowlands where there is also availability of high quality water.

At present, total irrigated land is somewhere between 30,000 and 50,000 ha and the main crops cultivated are: sugar cane (66%), rice (25%), bananas (3%) and other fruits, vegetables and basic grains (1%) (IEA-MARENA, 2001). In the Central region, surface waters do not cover the entire regional demand and groundwater sources are limited.

Cocibolca Lake has been considered a potential source for crop irrigation in the future, as it has an estimated irrigation potential of close to 15,000 Mm^3/year (IEA-MARENA, 2001).

3.3.1 Historical Background

1.82% of the Nicaraguan territory (2,372.73 km^2) is currently occupied in the cultivation of permanent crops. Irrigation agriculture began in the 1950's and the main irrigated land is found in the departments of León and Chinandega, on the perimeters of lakes Nicaragua and Managua, and in Nandaime-Rivas, as well as in the valleys of Sébaco, Estelí and Jalapa in the North-Central region.

At the beginning of the 1970´s the area with irrigation infrastructure was estimated to be greater than 40,000 ha, basically for irrigation by spraying and gravity, with an available groundwater volume under intensive exploitation of 1,076 Mm^3 (Table 9). By 1978, the irrigated surface increased to 70,000 ha. The use of automated spraying irrigation systems began in the 1980´s, although these systems are currently semi-abandoned (FAO, 1992).

Table 9. Groundwater Availability in 1973

Basin	Area (km^2)	Annual Available Volume (Mm^3)	
		1A	1B
León-Chinandega	1,548	462	528
Villa Salvadorita	217	29	54
Nagarote	562	54	114
Los Brasiles-Chiltepe	123	4	5
Tipitapa	938	44	118
Nandaime-Rivas	456	48	120
Sinecapa-Viejo	585	54	114
Sébaco-Darío	259	12	23
Total	4,688	707	1 076

1 A. Without substantial modification of the current conditions of the aquifer
1 B. Under "intensive exploitation"
Note: No information available from the Somotillo-Estero Real, North Coast of Managua Lake, Estelí and Jalapa Valley areas.

Source: Inventory and Property Register of Natural Resources 1973.

Regarding surface waters, a volume of 4,977,340 m^3 was planned to irrigate 36,970 Mz through six reservoirs (Table 10).

Table 10. Planned Use of Surface Waters (by Means of Reservoirs) in 1973

Place	River	Reservoir Volume[1] (m^3)	Irrigable Area[2] (Mz)
Mata de Caña	Villanueva	529,840	13,850
Mata Palo	Negro	1,109,660	10,840
Juigalpa	Mayales	201,600	2,830
Toro Negro	Sinecapa	304,140	1,890
La Calabaza	Grande-Matagalpa	1,645,110	3,220
Mal Paso	Villanueva	1,186,990	4,340
Total		4,977,340	36,970

[1] Collection volume based con estimates from the Bureau of Reclamation
[2] Based on an annual irrigation lamina of 1,750 mm per reservoir

Source: Diagnosis of Irrigation Potential, modified table, 1977.

Irrigated surface area increased until the year 1991 (Table 11). However, from then on, records report a fall, mainly as a result of pumping equipment deterioration by lack of maintenance (high import costs for spare parts) and lack of technical services for equipment operation.

Table 11. Progression of Irrigated Surface Area

Year	Area (ha)
1970	63,000
1985	86,000
1991*	93,000
1993	30,000
Estimate for 1996	61,000
Estimate1 1998**	61,000

* Historical maximum
** According to consulter

Source: CCO, 2001.

Likewise, increased energy fees and frequent interruption in energy supply have contributed to the decrease in irrigated area (CCO, 1998).

In 1991, agricultural groundwater use and needs were small compared to ENACAL extractions for domestic or industrial (Table 12). Potential water for irrigation from groundwater sources is estimated at 17,196 Mm^3 and from surface sources at 16.23 Mm^3, including Lake Nicaragua with 15,800 Mm^3, the Viejo River with 100 Mm^3 and three possible reservoirs with 100 Mm^3 (CCO, 2001).

Table 12. Use of Groundwater by Sector, 1991.

Sector	Extraction (Mm^3)
INAA/ENACAL	98.01
Municipal	6.65
Industry	5.88
Agriculture	1.24
Total	111.82

Source: Kokusai, Kogyo, 1993. Summary of Study of Water Supply in Managua.

In the Pacific region close to 30% of the potential groundwater is used together with 15% of exploitable surface waters. Most of the water collected (surface and groundwater) is used to irrigate 75,000 ha (CCO, 2001). Table 13 shows worldwide efficiency per irrigation method and water source with systems in good conditions. Efficiency decreases because of deterioration of spraying mechanisms, lack of leveling in gravity systems, and poor technical service and maintenance. Efficiency in rice irrigation systems is high due to soil permeability. Overall, irrigation system efficiency in Nicaragua is calculated to be less than 20%.

Table 13. Estimated Irrigation Efficiency per Type of System and Water Source

System	Water Source	Efficiency
Spraying/Pivot	Groundwater	63%
Gravity	Groundwater	51%
Rice	Groundwater	63%
Spraying/Pivot	Surface water	42%
Gravity	Surface water	34%
Rice	Surface water	42%
Source: PARH (1997): Plan de Acción de los Recursos Hídricos en Nicaragua.		

3.3.2. The State of Irrigation in Nicaragua

Eleven planning units called "current irrigable surface" which include irrigation infrastructure have been considered (Table 14), with a total surface of close to 61,000 ha. There are approximately 1,200,000 ha of available land at an altitude of up to 200 masl (Table 14). Taking water availability into account, especially the waters of Lake Cocibolca, an additional area of 230,000 hectares have been contemplated.

Table 14. Land Availability and Potential Irrigation Area; with Area of Maximum Potential Based on Available Land and Hydric Resources

Land Availability and Potential Irrigation Area		Area of Maximum Potential Based on Available Land and Hydric Resources			
Zone	Total Area (ha)	Regions	Source	Planning Unit	Area
Golf of Fonseca (Pacific)	162,800	North Pacific	Surface/ groundwater	1 and 2	71,000
Managua Lake (Central–Lacustrine)	138,300	Central Pacific Central	Groundwater	3 - 7	18,000
Cosiguina–Tamarindo (Pacific)	178,600	South Pacific	Groundwater	4	3,200
Carmen–Bahía Salinas (Pacific)	185,500	Lower North	Groundwater	11	800
Nicaragua Lake (Lacustrine)	436,700	Lower Central	Surface water	8 and 11	6,800
Inter-mountainous valleys	108,200	Lower South	Groundwater	9 and 10	13,000
TOTAL	1 ,210,100	Nicaragua Lake	Surface water	5, 9 and 10	120,000
		TOTAL	**70% Surface/30% Groundwater**		**232,800**
Source: CCO, 1998.					

3.4 Other Uses

Ninety four percent of Nicaragua's hydroelectric resources are concentrated in the Atlantic watershed. According to hydric availability, the potential for generating hydroelectricity has been estimated to be of up to 3,760 MW. Hydropower generation increased 8.0% in 2000 with respect to the total amount of energy generated until then, resulting in per capita use of 474 kWh. Although hydropower generation continues to rise, per capita consumption continues to be the lowest in the region.

3.4.1 Hydroelectricity

Because Nicaragua largely depends on imported oil to generate its electricity, the demand for electricity by both its population and the activities related to development, is only partially satisfied. In the year 2006, hydropower represented 10% of the electricity generated in the country. HIDROGESA, a public company, operates the two existing hydroelectric plants (Centroamerica and Santa Barbara). In view of these facts, the Ministry of Mining and Energy (MEM – Ministerio de Energía y Minas) has identified the renewable energy potential and level of use in the country, as shown in Table 15.

Table 15. Potential and Use of the Renewable Resources in Nicaragua.

Source of energy	Potential (mw)	Effective capacity (mw)	Percentage use (%)
Hydroelectricity	3,280	98	3.0
Geothermic	1,200	37	3.1
Wind	800	0	0.0
Biomass	200*	60	30.0
TOTAL	5,480	195	3.6

Source: MEM, Nicaragua, 2008.

The total water demand for energy generated by the projects identified by the MEM is estimated at 481 Mm^3 (FIG. 8.).

FIG. 8 shows the hydroelectric projects requiring a specific surface water volume provided by natural waterfalls or the damming of river water. The plants currently in operation, Centroamerica and Santa Barbara, rely on the diversion of the Tuma River in the 48m high Mancotal dam which forms the artificial reservoir of Lake Apanás. This reservoir has an average altitude of 956.5 masl, a surface area of 58 km^2, and a storage volume of 440 Mm^3, of which 310 Mm^3 are active storage thus allowing the regulation of the variable flow of the Tuma River.

SOURCE: MARENA, 2001, TAKEN FROM DE SILVA, 2002. HYDRIC CAPITAL AND USES OF WATER IN NICARAGUA.

FIG. 8. Hydroelectric Projects in Nicaragua; Source MEM.

Lake Apanás is one of the main reservoirs for the production of hydroelectricity. Its useful life and that of the Viejo River have decreased due to erosion of its basin. Likewise, the problems produced by the competition for the use of its waters in irrigation in the Sébaco Valley on one hand, and for generation of electricity by the Santa Barbara plant on the other, underline the importance of putting hydrologic plans per basin into practice (IEA-MARENA 2001).Table 16 shows the maximum estimated reservoir storage volume for hydropower generation for MEM projects.

All hydroelectric plants, those in existence and projected in the future, are located on the rivers of the Central and Atlantic regions because they provide the necessary conditions for their development. It is worth noting that the plants currently operating have decreased their production capacity in times of severe drought and also by erosion processes in the basins that have reduced storage volume by sedimentation. In addition, it is important to consider the long term effects of climate change once these projects have been approved.

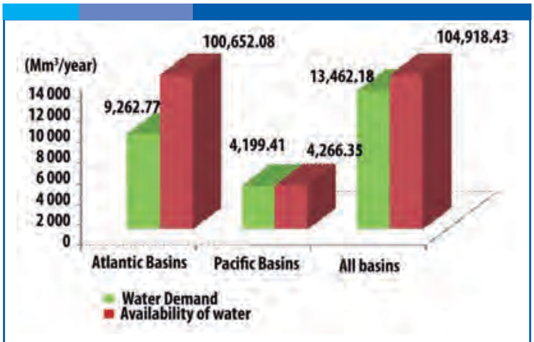
Table 16. Maximum estimated storage volume for reservoirs. Nicaragua (MEM –Ministerio de Energía y Minas), 2010.

Hydroelectric Project	Maximum reservoir volume (Mm^3)
Copalar	13 047
Tumarín	200
Mojolka	2 215
Boboke	10 360
Paso Real	25
Esquirín	20
Valentín	4 160
Piedra Fina	3.2
Pajaritos	1 281.64
La Estrella	18
El Consuelo	14
Piedra Puntuda	NR
Brito	1.6
Lira	2.95
Pantasma	0.524
El Salto	0.01
Centroamérica	30
Santa Bárbara	25
Larreynaga	0.18
La Sirena	131
El Barro	0.36

Source: Hydroelectric projects, Ministry of Energy and Mining of Nicaragua (MEM - Ministerio de Energía y Minas), 2010

3.5 Demand Versus Availability

National water availability is sufficient to cover the existing demand, as can be seen in FIG. 9. However, although availability is greater than demand in the basins draining into the Pacific, the existing difference is hardly significant, and thus will lead to issues of scarcity in the future. In fact, Basin N° 64 (between Cosigüiná and Tamarindo) already suffers shortages due to poor water distribution and overexploitation of the aquifer for use in agriculture, especially during the dry season (November to April) (MARENA, 2008a). Table 7 shows water demand according to estimated population per departament.



SOURCE: PHIPDA, 2003.

FIG. 9. Estimates of Total Water Demand in Mm^3/year.

Table 17. Estimated Current Population and Water Demand in the Country

Department	2010 Population (inhabitants)			Water Demand Year 2010 (Mm^3/year)	
	Total	Urban	Rural	Urban	Rural
Nueva Segovia	246,466	101,544	144,922	7.36	9.06
Jinotega	374,875	80,223	294,652	5.82	18.42
Madriz	146,964	45,118	101,846	2.94	6.37
Estelí	216,057	127,474	88,583	9.24	5.54
Chinandega	394,373	235,441	158,932	17.07	9.93
León	364,763	215,210	149,553	15.60	9.35
Matagalpa	518,004	193,215	324,788	14.01	20.30
Boaco	158,320	49,712	108,607	3.24	6.79
Managua	1,353,897	1,225,277	128,620	88.83	8.04
Masaya	317,044	175,642	141,401	12.73	8.84
Chontales	158,606	92,150	66,456	6.68	4.15
Granada	175,022	112,014	63,008	8.12	3.94
Carazo	175,410	108,228	67,182	7.85	4.20
Rivas	165,070	78,243	86,827	5.67	5.43
Río San Juan	111,361	27,283	84,078	1.58	5.25
RAAN	399,013	111,724	287,289	8.10	17.96
RAAS	325,347	120,053	205,294	8.70	12.83
Total	5,600,591	3,098,552	2,502,039	223.56	156.38
Total water demand					379.94

Source: Personal compilation based on population data from 2005 INEC Census and INAA Norms, 1999.

Water demand by municipalities, industry and agriculture is shown in Tables 18, 19 and 20.

Table 18. Per Year Municipal Use of Water, Municipal Gross Product and Population.

Year	Municipal Use (Mm^3/year)	Average Municipal Fee (US$/$m^3$)	Gross Internal Product Services (US$)
2005	116,713.5	0.34	0.89
2006	120,953.5	0.32	0.96
2007	123,514.5	0.31	0.00
2008	132,340.8	0.30	0.00

Source: ENACAL, Banco Central. Statistical Yearbook 2001-2008.

Table 19. Per Year Industrial Water Use, Gross Municipal Product and Fees,

Year	Water for Industrial Use (Mm^3/year)	Industrial Product (US$)	Industrial Water Fee (US$/$m^3$)
2005	6,996.0	4.13	0.88
2006	6,874.6	4.30	0.86
2007	6,894.2	4.46	0.83
2008	7,120.0	4.59	1.10

Source: ENACAL, Banco Central. Statistical Yearbook 2001-2008.

Table 20. Per Year Water Use in Agriculture, Municipal GIP and Fees.

Year	Water Use in Agriculture (mm³/year)	Agriculture GIP (US$)	Industrial Water Fee (US$/m³)
2005	-	0.95	-
2006	-	0.98	-
2007	-	0.96	-
2008	12 701.2	1.01	0.239

Source: MAGFOR. Subprograma Desarrollo y Reactivación del Riego para Contribuir a la Seguridad Alimentaria en Nicaragua. Statistical Yearbook 2001-2008. Banco Central, October 2008..

3.6 Natural Water Quality

3.6.1 State of Water Quality for Human Use

The natural quality for groundwater is considered to be fit for human consumption according to the quality norms in practice in Nicaragua (EPA, CAPRE). Three main hydrogeochemical water types are considered in these norms: HCO_3^- -Ca^2+, HCO_3^- -Ca^2+-Mg^2+ and HCO_3- -Mg^{2+} in all three areas in Nicaragua (Table 21). Regarding natural water contaminants, the most outstanding are iron and fluorine (10.5% and 0.9% of 1,488 samples, with values greater than 3.0 mg/L and 1.5 mg/L, respectively; UNICEF et al., 2005), as well as arsenic (Section 4.3.1). Water quality is mostly threatened in the Pacific region on account of the highly concentrated population and industry, in addition to the strong agricultural activity in this part of the country (OPS-OMS, 2004) (Section IV.1).

3.6.2 Classification of Water for Irrigation

Most water in the Pacific region is considered to be fit for irrigation. Table 22 summarizes the classification of water for irrigation from the Pacific region (Krásný, J., 1995). Thirteen types of water for irrigation have been classified per 1:25000 topographic maps in

Table 22. Classification of Water for Irrigation and its Distribution Area in the Pacific Region.

Topographic Map 1:250000 Class	Chinandega (km²)	Managua (km²)	Granada (km²)	Total (km²)
C1-S1	-	2 619.9	74.6	2 694.5
C2-S1	1 519.2	9 924.2	4 010.9	15 454.3
C3-S1	747.9	2 535.3	723.4	4 006.6
C4-S1	582.1	50.2	10.0	642.3
C1-S2	-	-	-	-
C2-S2	-	75.0	11.3	86.3
C3-S2	16.5	158.1	53.8	228.4
C4-S2	1.8	32.8	5.3	39.9
C1-S3	-	-	-	-
C2-S3	-	2.0	-	2.0
C3-S3	-	52.8	-	52.8
C4-S3	2.2	43.4	7.3	52.9
C1-S4	-	-	-	-
C2-S4	-	-	-	-
C3-S4	-	45.0	-	45.0
C4-S4	1.3	52.0	16.1	69.4
Total (km²)	2 871.0	15 590.7	4 912.7	23 374.4

Source: Krásn□J., 1995.

Table 21. Hydrogeochemical type, pH and electric conductivity

Area of the Country	Predominant type of water		Second most predominant type of water		pH		Electric conductivity (µS/cm)	
Pacific	HCO_3- -Ca^{2+}	*	HCO_3- -Ca2+-Mg^{2+}	*	6.18 –8.80	***	‹ 500	***
Central	HCO_3- -Ca^{2+}	**	HCO_3- -Mg^{2+} HCO_3- -Mg2+-Ca^{2+}	**	(Norte) 4.20 – 9.96 (Sur) 4.83 – 9.42	***	‹ 500 – 3.550	***
Atlantic	HCO_3- -Ca^{2+}	**	HCO_3- -Mg^{2+}	**	5.6 – 9.40	***	‹ 500	***

Source: *INETER, 1989. **INETER, 2004. ***UNICEF et al., 2005.

Table 23. Surface Areas of Types of Water for Irrigation in Estelí, San Carlos, Juigalpa, Siuna and Bocay Maps.

	Area of topographical maps scale 1:250,000 (km²)						
Classes	**Estelí**	**San Carlos**	**Juigalpa**	**Siuna**	**ocay**	**Total**	**Area (%)**
C1-S1	4,442.66	3,285.63	6,130.49	16,747.17	8,981,11	39,587.06	53.215
C1-S2	389.89	929.37	120.51	11.25	0,00	1,451.02	1.951
C1-S3	126.80	130.01	0.00	0.00	0.00	256.81	0.345
C1-S4	5.62	230.25	0.00	0.00	0.00	235.87	0.317
C2-S1	5,457.18	4,483.38	7,388.91	1,087.71	1,594.98	20,012.16	26.901
C2-S2	1,566.94	1,314.16	2,335.81	107.12	0,00	5,324.03	7.157
C2-S3	522.96	528.82	904.62	0.00	0.00	1,956.40	2.630
C2-S4	363.43	381.06	1,084.21	10.33	0.00	1,839.03	2.472
C3-S1	474.23	564.58	48.35	5.32	0.00	1,092.48	1.469
C3-S2	420.93	1,029.99	0.00	0.00	0.00	1,450.92	1.950
C3-S3	241.63	466.12	0.00	0.00	0.00	707.75	0.951
C3-S4	96.21	344.33	36.73	0.00	0.00	477.27	0.642
C4-S1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C4-S2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C4-S3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C4-S4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total						**74,390.80**	**100.00**

Source: Krásn□, J., 1995.

the Central regions and part of the Atlantic (Table 23), 50% of which belong in types C1-1, C2-S1 and C2-S2.

Of the total area studied (Table 24), 85.06% can be widely used for irrigation of all crops without restriction, except for those extremely sensitive to salinity (INETER, 2004).

4. The Environmental Situation of Hydric Resources

Pollution of surface and groundwaters is prevalent throughout the country as a consequence of agriculture, discharge of non-treated domestic, industrial and agro-industrial wastes into lakes and rivers, and

Table 24. Area of Water Class Without Restriction for Irrigation Compared to Total Area Studied.

Total Area Studied	**Without Restriction**					
	Pacific		Central and Atlantic		Total	
(km²)	(km²)	(%)	(km²)	(%)	(km²)	(%)
97,765.20	18,235.10	18.65	64,923.25	66.41	83,158.35	85.06

Source: INETER, 2004.

erosion resulting from changes in land use. In addition, the loss of forest coverage is producing excessive discharge of sediments into bodies of surface water, causing an increase in eutrophication, enhanced by the accompanying nutrients.

4.1. Impact on Agriculture

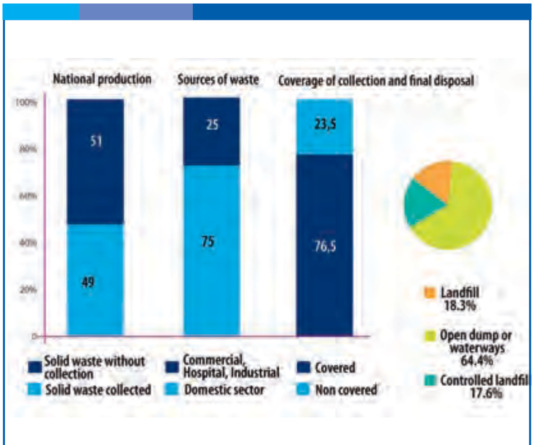
In Nicaragua, inadequate farming practices are the main cause of surface and groundwater contamination. In the Pacific and Central regions where most agricultural activity occurs, there have been issues related to contamination by agrochemicals in both surface and groundwaters, especially in the León-Chinadega aquifer, the most important in the country. In this area, organochlorinated pesticides (used in cotton monoculture) and organophosphorus pesticides as well as triazines and carbamides have been found (Alvarez, 1994; Briemberg, 1995; INETER/OIEA, 1997; CIRA/MEL/DIPS, 1996-1998; CIRA/IAEA, 1999; CIRA/UNAN, 1999a y b; Centro Humboldt, 2002; Delgado, V., 2003). Unfortunately, there are few studies related to the Atlantic region.

Dumailo (2003) performed a comprehensive study of the Bluefields Bay, the mouth of the Escondido River, and identified pollution from hydrocarbons, pesticides and pathogenic bacteria. There are plans to establish a monitoring system to reduce the drainage of pesticides into the Caribbean region (Section 4.3). To date, there are 1,446 agrochemicals registered in Nicaragua, of which 23% are fertilizers, 16% herbicides and pesticides, and 15% fungicides. Eighty five percent of the pesticides are used in agriculture, 10% for public health and the rest for domestic and livestock uses, as well as the control of illegal crops (MAGFOR, 2004). From 2004 to 2009 a total of 16,290,666.45 kg of pesticides was imported; of these, 61.87% are herbicides, 26.58% fungicides and 10.45% insecticides (Proyecto RepCar, 2010). Until 2006, the approximate use of pesticides was 15 metric tons. The increase has been caused by greater land use for crops and use in agriculture and cattle to combat pests and diseases which affect yield (PNUMA-MARENA, 2000). Residues from these products represent a permanent risk to the quality of hydric resources.

Currently, 90% of farmers in the country use pesticides and only 10% are trying alternatives that are friendlier to the environment and human populations (PNUMA-MARENA, 2000). It is estimated that pesticide flow into the Caribbean Sea has reached 13 metric tons of active ingredients per year. This, together with the rapid movement of the agricultural border towards the Atlantic basin, has increased the risk of pollution to the diverse but fragile natural reserves and marine ecosystems within the Atlantic shelf and the Greater Caribbean in general (OPS/OMS-DANIDA, 2002).

4.2. Impact of Industry and Domestic Activities on Hydric Resources

According to figures from the Ministry for the Environment and Natural Resources (MARENA - Ministerio del Ambiente y los Recursos Naturales) inventory, more than 275,000 tones domestic garbage area produced annually in the Pacific region, and close to 60,000 tones industrial waste are abandoned in areas with no regulation whatsoever. FIG. 10



SOURCE: AGENDA 21-NICARAGUA.

FIG. 10. Estimated Solid Waste Management Throughout the Nation.

shows an estimate of nationwide solid waste management. Seventy five percent of collected solids are domestic in origin and the remaining 25% come from businesses, hospitals and industry. Managua City produces 61% of the waste collected throughout the country.

Municipal dumps receive industrial solid wastes that have not been previously classified. Polluting substances eventually reach groundwater sources or surface currents. Hospital wastes are mixed with solid wastes and also sent to municipal dumps; although some medical centers have incinerators (MARENA, 2004). Shows Production of Solid Wastes Per Industrial Sector Nationwide. A great amount of non-collected waste is swept by currents into bodies of water; of these, Xolotlán Lake in the city of Managua stands out as it receives 260,000 tons of urban solid wastes per year. Waste from homes is mixed in the sewer system with waste from laboratories, hospitals, industry and businesses, without any prior treatment in most cases.

The most affected lake again is Lake Xolotlán, into which contaminated discharge from the city of Managua has been dumped since 1926, at an estimated rate of 1.75 m^3/s.

Sewage system coverage and treatment is shown in FIG. 12 , and it is worth noting that 50% of wastes were treated up to the year 2005. However, the operation of many treatment systems is poor as they discharge effluents that do not comply with the regulations for control of pollutants from domestic, industrial and farming (Decreto33-95; La Gaceta, 1995) as a consequence of greater polluting discharge by an increasing population.

Table 25 presents total phosphorus (TP),

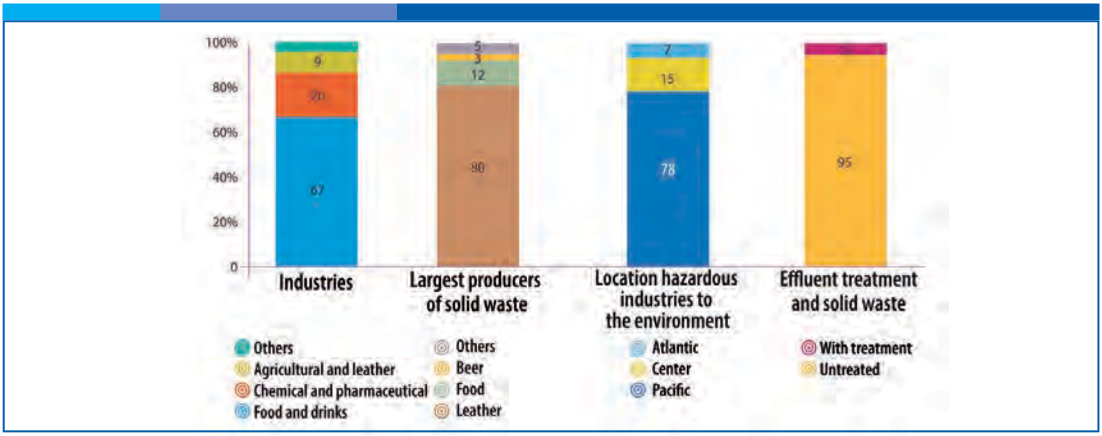
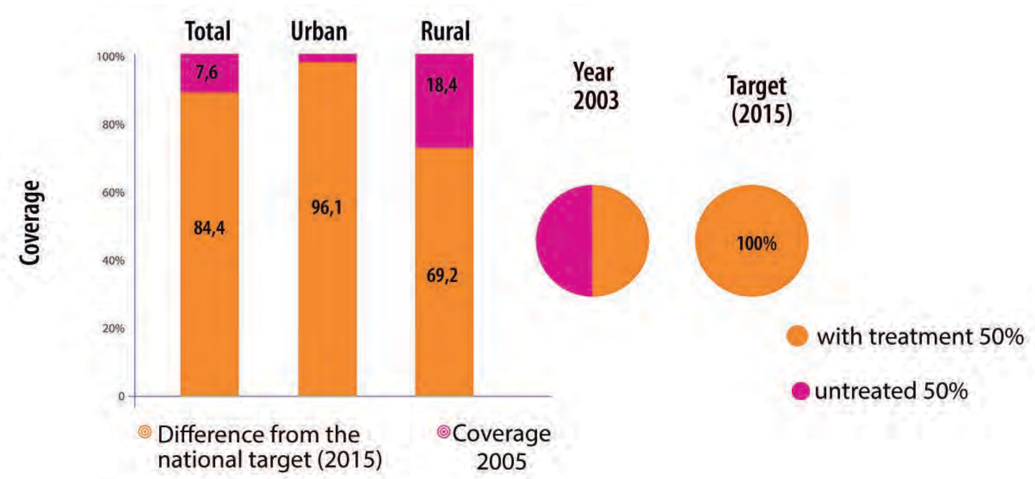


FIG. 11. Shows Production of Solid Wastes Per Industrial Sector Nationwide.

chemical oxygen demand (COD) and suspended solids (SS) in three municipal effluents that discharge into natural receiving bodies. In all cases, COD and SS do not fulfill the values established in decree 33-95 (180 mg/l and 80 mg/l, respectively).The new regulation for pouring of residual waters into receiving bodies and sanitary sewerage, yet to be in put into practice, determines a figure of 10 mg/l for TP, which is considered to be very high as it promotes eutrophication in surface waters.

Aquatic ecosystems such Lake Xolotlán and the lagoons of Masaya and Tiscapa are highly eutrophized and consequently have become useless. As part of the project to save and reclaim Lake Xolotlán, a new residual water treatment plant began operating in February 2009, treating 75% of the total volume of residual waters produced by the city of Managua.

Table 26 shows some aquatic ecosystems that receive crude liquid and solid wastes thus breaking down the resource and limiting its use.



SOURCE: INEC, 2005

FIG. 12 . Sewage Coverage and Treatment %.

Table 25. TP, COD and SS results in Effluents for Municipal Waters.

City	Type of Effluent	TP (mg/l)	COD (mg/l)	SS (mg/l)	Body Receiving Polluting Discharge
Boaco	Untreated effluent	25.09	1,690.14	1,253.00	Fonseca River
Granada	Effluent from oxidation lagoons	10.11	306.73	147.00	Cocibolca Lake
Rivas	Effluent form oxidation lagoons	16.33	237.87	165.71	Río de Oro

Source: CIRA/UNAN, 2007.

Table 26. Bodies of Water Receiving liquid and Solid Wastes.

Body of water	Wastes			
	Solid		Liquid	
	Domestic	Industrial	Domestic	Industrial
Acome River(Chinandega)	x		x	
Atoya River (El Viejo)	x	x		
Chiquito River (León)	x	x	x	x
La Zopilotera River (Chichigalpa)	x	x	x	x
El Realejo Estuary	x			x
Xolotlán	x	x	x	x
Tiscapa	x		x	x
Xiloá	x			
Cocibolca	x	x	x	x
Masaya			x	
Río de Oro (Rivas)	x		x	
Fonseca River			x	
Malacatoya				
Mayales	x		x	
Acoyapa			x	
Tepenaguasapa			x	x

Source: CIRA/UNAN, 2007, Flores, S., 2005, MARENA, 2004c, and MARENA, 2003.

4.3. Impact of Heavy Metals

Contamination by heavy metals from both human and natural sources has been the cause of the most important pollution problems with respect to the quality of hydric resources (UNICEF, 2004; Altamirano, 2005). Certain areas in the Central and Northern regions are polluted by arsenic from natural sources, while craterous lagoons in the Pacific, such as Apoyo, Xiloá, Asososca de León and Apoyeque also have high levels of arsenic (Parello et al., 2008). Mercury used in small-scale mining, chromium used by tanneries and the lead used in the production of batteries are examples of metal pollutants of human origin.

4.3.1. Problems Caused by Arsenic

Arsenic causes natural contamination of groundwater in certain areas of the country as a consequence of the presence of volcanic formations. The main sources of arsenic are mineralized or hydrothermally modified tectonic structures found parallel to the Nicaraguan Graben, while faults and fractures near the flow of groundwater allow the pollutant to enter the aquifer (Altamirano y Bundschuh, 2009). FIG. 13 shows the location of seven drinking water sources with arsenic concentrations above the norm (>10µg/l, WHO) according to several monitoring campaigns by the Center for Research on Aquatic Resources of the National Autonomous University of Nicaragua (Centro para la Investigación en Recursos Acuáticos de la Universidad Nacional Autónoma de Nicaragua) (CIRA/UNAN). A study on the presence of arsenic in groundwater in the Northwest and Southwest regions of Nicaragua (Estrada, 2002) focused mainly on water sources near mineralized bodies altered by hydrothermal events in tectonic structures parallel to the Nicaraguan depression and found five anomalous areas (El Zapote, Santa Rosa del Peñón, La Cruz de la India, Susucayán and Rincón de García) with an arsenic content greater than 10 µg/L. All of these wells are found in extremely poor areas.

4.3.2. Problems Caused by Mercury

Mercury is considered to be the contaminant of human origin with the most serious environmental impact in the world. In Nicaragua mercury is mainly used in uncontrolled amalgamation and distillation activities involved in gold mining, resulting not only in pollution of the environment but also human exposure to the element (Lacerda, 2003; Telmer et al., 2006). Although gold mining activities have declined and represent <0.8% of Nicaragua's GIP, there are still two large and three small active mining companies. The use of mercury in amalgamation is concentrated mainly in small-scale mining in Santo Domingo, Distrito de Coco Mina and Bonanza. The total mercury emitted by Nicaragua in the past 100 years is estimated at 40 tons (Andre et al., 1997), and recent annual emissions vary from 60 to 180 kg (Andre et al., 1997, and Velásquez, 1994). Likewise, Lake Managua has been affected by liquid wastes with high content of mercury from the Hercasa-Elpesa (Pennwalt) complex which operated from 1967 to 1992 along the south coast of the lake, and produced sodium hypochlorite and chlorine gas.

SOURCE: ALTAMIRANO AND BUNDSCHUH, 2009.

FIG. 13 . Location of Seven Drinking Water Sources with Arsenic Concentrations Above Norm (›10µg/l[-1], WHO).

The Sucio River, a small river historically exposed to gold mining activities in the municipality of Santo Domingo, Department of Chontales, has been studied in relation to the impact of mercury on hydric resources. Here small-scale miners and mining cooperatives still use mercury to enrich gold. Mercury has been found suspended in the waters of the river at concentrations varying between 0. 1µg/L to 5µg/L in accordance with the operation of gold processing plants and the distance from the amalgamation centers. These values are greater than the criteria established by the WHO for water fit for human use. Mercury was also detected in groundwater, as well as in the river sediments at concentrations of 10μg/g two and three km downriver and values of 0.1μg/g forty five km from the discharge source of the two treatment plants. Nevertheless, the risk of contamination of drinking water is low as it is limited to the area near to the processing plants (Picado, 2008). Residual waters containing large amounts of mercury from the Hercasa-Elpesa (Pennwalt) complex were discharged into Lake Xolotlán without any kind of treatment for years.

This complex has been estimated to have poured approximately 18,000 kg (40 tons) of mercury into the lake, representing one of its main sources of pollution (Corrales, et al., 1982). Recently, Japan's National Institute For Minamata Disease and the CIRA/UNAN performed the study "Environmental Pollution by Mercury in Lake Xolotlán in Nicaragua, in Relation to an Assessment on Human Health" financed by the Inter-American Development Bank (IDB). This report determined the amount of mercury in water, soil and sediments, as well its bioaccumulation in human hair and fish in the south micro-basin of Lake Xolotlán. The results indicate that in the monitored area (the land on which the factory is found and surrounding areas) both soil and water are polluted with mercury. In addition, mercury and methyl-mercury were found at the bottom of a channel used to pour liquid wastes into the lake. Local residents that regularly consume fish, did not show levels of mercury in hair or visible epidemiologic effects; the mercury content in fish also proved to be low (Jiménez et al., 2009; Nicaraguan Research Center for Aquatic Resources, 2007).

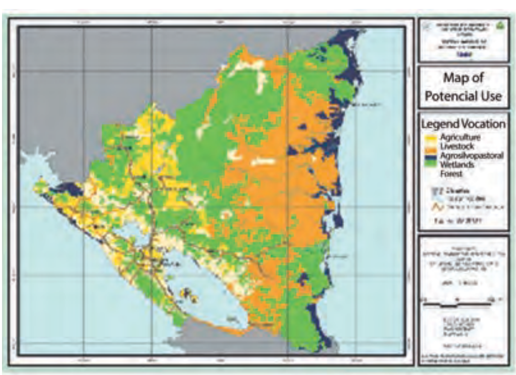
4.4. Impact of Pollution by Erosion

It has been calculated that between 1990 and 2015, the population of Nicaragua will have increased nearly 67% (Vargas, 2007) with most of this growth occurring in urban areas (the country's urbanization rate is the highest in Central America with 50% urban population in 2005).

Such growth, in synergy with deficient sanitary structure (for both solid and liquid wastes), a high population density, poverty and a lack of land zoning plans, has caused deterioration of the environment which in turn is reflected in water quality. Deforestation of hydrographic basins is occurring very quickly. In 1950, Nicaragua had 7 million ha of forests, which by 2006 had been reduced to only 3.2 million (Vargas, 2007). The cause of deforestation has been the use of land for farming (FIG. 14.), which has produced erosion of hydrographic basins and extensive use of pesticides. The conversion of forestland into extensive land for livestock is common in the Colciboca Lake basin, where grassland for pasture is calculated to be 75.1% (Vammen et al., 2006). In 2000, the surface covered by forests was 56,195 km^2 (43.1% of the national terrritory), 48,875 km^2 or 37.5% of which was being used for farming. In an assessment on potential land use (FIG. 15) 55.3% was catalogued as apt for forest use, while the remaining 44.7% was considered adequate for livestock and only 6.9% for agriculture (MARENA, 2004a y b). These figures contrast with actual landuse and have resulted in pollution of surface waters by sedimentation, eutrophication and pesticides, and of groundwaters by pesticides in certain basins.

SOURCE: MAG-FOR, 2002.

FIG. 14. Map of Forests Bordering with Agricultural Areas.



SOURCE: MAG-FOR, 1997.

FIG. 15 . Map of Potential Use.

4.5. Impact of Hydraulic Works on Hydric Resources

The building of reservoirs has been promoted along certain rivers as an important source of hydroelectricity and water supply for human settlements. Generally, reservoirs in Nicaragua are vital for the life and development of the populations living in the area and are used to provide fish, recreation, water for irrigation and to generate electricity. The problem is however, that the construction of dams is always associated to serious deforestation and subsequent erosion and sedimentation, as well as silting of the basin, all of which reduce the potential for electricity production of the reservoir and other uses due to variation of the quantity and quality of water. Some Nicaraguan reservoirs have been modified by rapid silting and eutrophication caused by the arrival of allochtonous matter from the basin (agriculture, and domestic and industrial discharge). As mentioned above, the building of reservoirs produces benefits such as the generation of electricity, increased biomass production (fish and aquaculture), storage of water, recreation, tourism, increased irrigation potential and water reserve for supply. Among the negative effects are the relocation of human populations, migration of individuals to the construction area, loss of native fish species, loss of land due to flooding, loss of river biodiversity, reduction of water flow, loss of agricultural land, changes in the chemical composition of water, formation of barriers to migration of fish and reduction in water quality. However, the greatest problem is the environmental impact that results from altering river flow as it directly affects soil, vegetation, fauna, fish and above all, human populations in the lower part of the basin.

In Nicaragua some reservoirs have been built to generate hydroelectricity such as the Apanás-Asturias Lake which results from damming the Tuma River and generates electricity distributed nationwide by the Centroamérica plant. Deforestation associated to Lake Apanás is a consequence of poor land use and has produced a great amount of erosion along with washing and depositing of soil particles into the basin. On the other hand, there has been a decline in water quality and an increase in eutrophication in Lake Apanás not only because of deforestation, but also due to agriculture, domestic and industrial waste and the lack of sanitation. Another example worth mentioning is Las Canoas reservoir, built in the 1980s to irrigate Tipitapa-Malacatoya sugar cane plantations, generate electricity and as a source of fish for the nearby communities. Today, as in Lake Apanás, water levels in the reservoir have decreased because of poor winters. Consequently, the existence of these reservoirs is at risk and causes tension among the users competing for the resource, not only because thousands of small and mid-scale farmers in the region depend on these waters, but also because the water is needed by a large part of rice crops in the lower areas of the basins.

4.6. Some Specific Pollution Problems in the Country

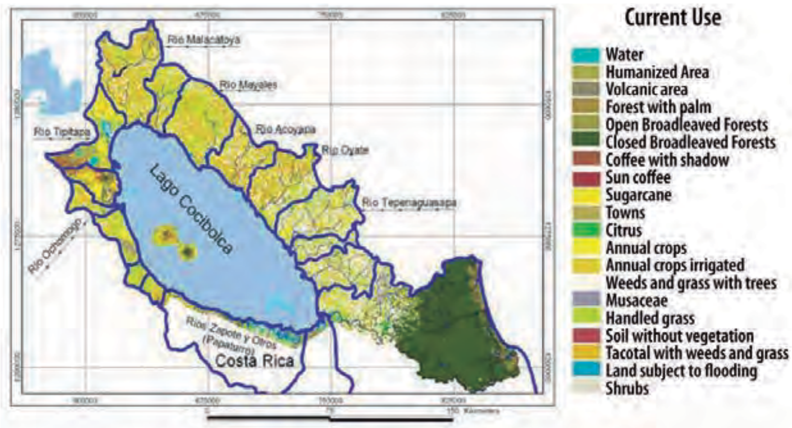
4. 6.1. Basin Nº 69, San Juan River

Basin N° 69 includes the San Juan River and the great Nicaraguan lakes, Lake Xolotlán and Lake Cocibolca that are part of the most important hydric resources in the country and key factors for its development. As mentioned earlier, Lake Colcibolca has in addition been declared as national drinking water reserve; its average flow into the San Juan River (475 m^3/s) is not currently used.

4.6.1.1. Lake Xolotlán

The pollution present in Lake Xolotlán (also known as Lake Managua) has drastically limited the use of its waters. The capital city of Managua, with 24.4% of Nicaragua's population (1,335,204 inhabitants) in 2009, is located on its southern shore. The lake has a surface of 1,016 km^2 and a basin of 6,668 km^2 (Hydrobiological Bulletin, 1991). As mentioned above, since 1927 it receives rainwater in addition to untreated industrial and domestic sewage waters. Deforestation in the northern and southern areas of the basin has also contributed nutrients and solids to the lake as a consequence of erosion. Currently, water from the lake cannot be used directly for human use nor can it be used for irrigation due to high mineral concentration (total dissolved solids). Likewise, the input of liquid wastes from the city has created an unbearable situation relative to odor and bacterial charge, limiting all uses, including direct contact (CIRA/UNAN, 2008). In order to allow the lake to recover to a level classified as non-contact recreation, ENACAL has installed a treatment plant inaugurated in 2009.

However, Lake Xolotlán not only receives waste waters from the city, but also pollutants from the municipal dump, called La Chureca. This dump originated spontaneously and unplanned in 1972 as a rubble deposit to receive debris from the earthquake that devastated the city in that year. Currently the dump has a surface of 47 ha and receives 1,200 tons of untreated and unclassified solid wastes daily (CIRA/UNAN, 2009). The "Impact Assessment of Leachate from the City of Managua Landfill called La Chureca, to the Waters of Lake Xolotlán, to the Aquifer Affected and to Acahualinca Lagoon" project found evidence of infiltration of leachates into the subsoil and lake. The presence of leachates in Lake Xolotlán has caused pollution by recalcitrant organic substances and minerals, compounds which make reclamation of the lake even more difficult. The problem is serious, as solid wastes can



SOURCE: VAMMEN, 2006. MAP BY YELBA FLORES.

FIG. 16. Land use in the basin of the San Juan River. Lake Colciboca Region.

be found directly in the lake when its waters are highest during the months of heavy rainfall. By means of the "Comprehensive Development of the Acahualinca District (Managua)" the Mayoralty of Managua in coordination with the Spanish Agency for International Cooperation for Development (AECID - Agencia Española de Cooperación Internacional para el Desarrollo), is currently developing a proposal to reduce the effects of leachates both in the lake as well as in the groundwater. The project includes sealing the dump, installing a leachate treatment plant and the proper classification of solid wastes reaching the landfill.

4.6.1.2. Lake Cocibolca

Lake Cocibolca is the largest body of surface water in Central America and is also the largest tropical lake in the American continent. It has a highly important hydric potential for Nicaragua, as its waters are of good quality and fit for human use. It is worth mentioning that the average flow at its only outlet at San Carlos, the start of the San Juan River, is 475 m^3/s or 41 Mm^3/d as calculated by INETER. Limnologic studies by CIRA/UNAN have revealed the speeding up of eutrophication processes in recent decades. This has been detected as an increase in phytoplankton biomass, structural simplification of phyto- and zooplankton, and the predominance of cyanophytes, blue-green algae that are eutrophication indicators. (Procuenca San Juan, 2004a y b).

These changes have been brought about by the increase in macronutrient flow from tributaries, the basins of which have suffered deforestation, as well as the conversion of extensive areas for livestock pasture (FIG. 16) and the resulting erosion (Vammen, 2006).
The main tributaries of Lake Cocibolca in Nicaragua, the rivers Malacatoya (in its three sections), Mayales, Acoyapa, Oyate, Piedra (mid-section), Camastro, Tule and Sapoá contain total phosphorus concentrations above those that are recommended by the Environmental Protection Agency (EPA) to avoid eutrophication in lotic bodies of water (fast moving) (CIRA/UNAN, 2007). The EPA recommends the total phosphorus (TP)

guideline value of 0.05 mg/l for all currents entering a lake or reservoir. All surface flows discharging its waters into Lake Cocibolca are used as drinking troughs, for crop irrigation (Malacatoya River), and receive various discharges from municipalities (Mayales River), as well as wastes from dairy processing and tanneries, among others. The waters of Lake Cocibolca are used to flood extensive areas dedicated to growing rice while the ecosystem itself receives the irrigation return water. Data obtained by CIRA/UNAN from 2002 and 2003 on the nutrient loading of surface waters in Lake Cocibolca, show that the Oyate and Tepenaguasapa tributaries found on its eastern shore are the main contributors of phosphorus pollution with 41 and 123 tons per year respectively, as well as nitrogen pollution with 123 and 345 tons per year respectively. This equals 92% of the total received by the ecosystem through rivers. Results show that greater input occurs during the first rains when soil lacks vegetation in areas used for farming activities (Flores, S., 2005).

The General Law for National Waters recognizes the importance of adopting measures to avoid the degradation of waters in the basin: "the lake must be considered a natural clean water reserve of high national interest and priority, and it is necessary to establish the specific mechanisms and regulations that guarantee and regulate water productivity, while simultaneously ensuring the maintenance and increase of flow that allow the development of economic activities, without detriment to the quantity and quality of water production, forbidding introduction and culture of exotic invasive species, as well as avoiding contamination of the resource and the deterioration of the ecosystem by industrial and domestic effluents" (General Law for National Waters, Law 620, La Gaceta, 2007b). The National Assembly also ordered the establishment of the "Commission for the Sustainable Development of the Lake Cocibolca and San Juan River Basin" for the purpose of preparing the Plan for Comprehensive Management for Basin N° 69.

4.6.2 Basin Nº 64

Basin N° 64 is found in the northwest of Nicaragua, between the Cosigüina volcano and the Tamarindo River (Figure 3) and contains the most productive aquifers in the country (27.5 x 10^9 m^3; UN, 1974). The aquifer covers an area of 1,300 km^2 and sustains a population of nearly 700,000 inhabitants (16% of the total population of Nicaragua), as well as the most extensive and fertile land for agriculture in the nation. Productive activities mainly involve growth of agricultural exports by monoculture and intensive mechanization. The main crops currently at risk and produced for export are sugarcane (65%), peanuts (29%) and bananas (6%); these receive a large quantity of agricultural chemicals and are irrigated by 74.4% of the water extracted from the aquifer (MARENA, 2008a y b). Because the León-Chinindega aquifer is shallow and unconfined, it is highly vulnerable to pollution by pesticides. Between 1950 and 1980, the most widely used pesticides were highly persistent organochlorines. From 1973 to 1981, 70,270 tons of pesticides were applied, 80% for the growing of cotton (Briemberg, 1994). Several studies have shown the presence of dieldrin, pp-DDT, pp-DDE, pp-DDD, and toxaphene above the norm for drinking water at depths of 12 meters below the water table in three sample wells located in various fields, historically used to cultivate cotton (Delgado, 2003). These compounds were also found in soils (Briemberg, 1994; CIRA/UNAN, 1999a; Centro Humboldt, 2001). The León-Chinandega aquifer in addition includes a deeper system that is recharged in the mountains, while the shallow system is recharged from the central plain (UN, 1974).

The deeper aquifer is highly vulnerable to climate change and to flow conditions of the local rivers. Agro-chemicals found in the shallow system are a risk to the deeper aquifer due to greater pumping of water or drought conditions that reduce river volume and promote water exchange between the two systems (Delgado, 2003; CIRA/UNAN, 1999b, and Calderón, 2003). Pollution assessment of aquifer vulnerability shows that it increases during rainy years (MARENA, 2008a), especially during extreme events such as hurricane Mitch, as floods carry all kinds of contaminants to wells. The aquifer also is very dynamic as a consequence of its great permeability. A toxicological analysis of the soil and waterwells in the Posoltega area performed after hurricane Mitch found organochlorinated pesticides in concentrations above the EPA norm in eight wells and organophosphates in eleven wells (CIRA/UNAN, 1999a).

4.6.3 Contamination of the Caribbean Watershed

The rapid spread of the agricultural border to the Caribbean coast (Figure IV.5), soil erosion caused by fast deforestation, and the wide use of pesticides in agriculture have together generated an increasing concern relative to pollution in ecosystems and draining of toxic substances into rivers, coastal lagoons and fisheries next to the Caribbean Sea. As 93% of the country's surface waters flow into Nicaragua's Caribbean coast, the "Monitoring of Pesticide Runoff into the Nicaraguan Caribbean" project is being put into action by CIRA/UNAN, under the coordination of MARENA and within the framework of the regional project "Colombia, Costa Rica and Nicaragua; Reducing Pesticide Runoff in the Caribbean Sea" (Proyecto RepCar, 2009). In this way, information on runoff and impact of pesticides along the Caribbean coast will be available, concretely with respect to the outlet of three basins: (a) Basin N° 45 Coco River (bi-national basin shared with Honduras where the Coco or Wangki River hydrographic system, the longest in the nation, is found); (b) Basin N° 61 corresponding to the Escondido River (connected to the coastal lagoon known as the Bluefields Bay, which receives pesticides applied on crops in the northern part of the basin, and (c) Basin N° 63 between the Escondido River and Punta Gorda (where a large part of the population from the Región Autónoma Atlántica Sur-RAAS lives).

5. Water and Sanitation

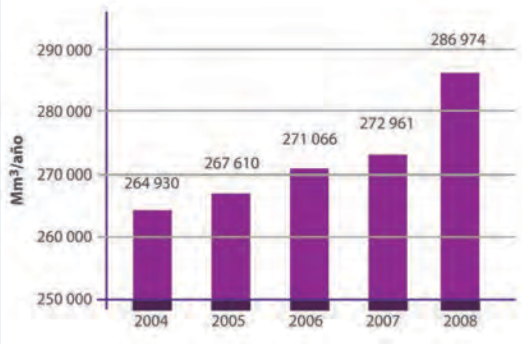
5.1 Water Demand for Human Consumption

Nicaragua has experienced a significant demographic expansion in the past 50 years; its population has grown from 1,049,611 inhabitants in 1950 to 5,142,098 inhabitants in the year 2005 (INEC, 2005).

According to projections on population growth, demography in the country is expected follow the same pattern in 2010, therefore water demand is expected to rise accordingly. Considering population data and the rate of population increase in the most recent census (INEC, 2005), the current population in Nicaragua is estimated at 5,600,591 inhabitants who require 379.94 Mm3 of water per year. According to the 2001 State of the Environment Report (Informe del Estado del Ambiente), ENACAL estimated the demand in 2010 to be 340 mm^3. In order to estimate water demand, the provision recommended by NTON 09003-99 norm of the Nicaraguan Institute for Aqueducts and Sanitation (INAA - Instituto Nicaragüense de Acueductos y Alcantarillados) was considered and a 25% loss was assumed. Table 17 shows population estimates and water demand per department for the year 2010.

Precise official data on water demand are lacking, because the existing water demand is not covered in its totality by the Aqueduct and Sanitation Distribution Company (ENACAL). According to the most recent data, drinking water coverage is 85% in urban areas, and there is thus a gap between water demand and supply services. Nevertheless, the distribution company has made the necessary effort to increase water supply. FIG. 17 shows an increase of 9.23% in water production by ENACAL in the period from 2004 to 2008.

According to data from ENACAL (2007), 71.7% of the Nicaraguan population has drinking water infrastructure, either through a dwelling or a communal connection. The nation's urban areas are supplied by 155 distribution stations covering 180 communities. The WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation states that Nicaragua covered 98% use by means of improved water sources in urban areas, while it only covered 68% in rural areas in 2008. Piped water, the most adequate system to improve the health of the population, reached 88% in 2008 in urban areas, and only 27% in rural ones (PCM, 2010).



SOURCE: SINIA-MARENA, 2009.

FIG. 17. Clean Water Production ENACAL period 2004-2008.

5.2. Supply Networks in Urban Areas

According to figures by ENACAL in the draft for the IV Report on the State of the Environment (SINIA-MARENA, 2009), 85% of urban population has access to clean water services through supply network systems, which means that within urban areas there is still a considerable percentage of the population with no access to drinking water, whether it is because these persons are not registered or because they are supplied by other means.

Likewise, groundwater is the main clean water supply source because most the population and the main towns and cities are located in the Pacific region, where surface water is hardly available and there are great deposits of groundwater.

This situation forces exploitation of groundwater as the main supply source, consequently increasing distribution costs due to the energy needed to collect and send water through the network, therefore limiting development of the sector because of high investment costs. In the country, clean water is supplied in urban areas by ENACAL, the decentralized companies AMAT (Empresa Aguadora de Matagalpa) and EMAJIN (Empresa de Acueductos y Alcantarillados de Jinotega), in addition to several municipalities and private land developers. ENACAL manages 76% of the clean water systems in the country. Table 27 summarizes information for the 222 drinking water supply systems, 154 of which come from groundwater.

Most of the networks for drinking water supply in the country are in poor condition, affecting the quality of service, specifically continuity of supply. ENACAL, the country's water distribution company, reports that the main supply problems are caused by the following factors: limited or no maintenance of the network system or pumping equipment, high degree of leakage due to obsolete distribution networks, frequent and lengthy power interruptions, unorganized network growth and not less importantly, the gap existing between water production and increasing demand by the population.
According to the Executive Head of ENACAL, more than half of its users receive water partially (a few hours a day) and nearly half of the country's population does not receive services from the company. Only 46% of the 286.97 mm^3 of water supplied annually by ENACAL are billed, thus restricting development in the sector because of lack of resources for investment (ENACAL, 2008a). Service quality is most affected from 7:00 am and 5:00 pm when demand is highest, mainly due to issues with pumping pressure and the existing deficit between supply and demand.

Problems concerning service continuity become acute during the dry months, the most difficult being February, March, April and May, when water rationing plans must be implemented not only in the capital, but also in the remaining departments of the Pacific and Central regions (FAO-CEPAL, 2009).
Between 2002 and 2007, ENACAL invested US$167,669.30 in clean water and sanitation

Table 27. Number of Supply Systems per Type of Supply Source.

Distribution Companies	Number of systems	Number of systems per type of effluent		
		Groundwater	Surface water	Combination of both
ENACAL	169	138	23	8
AMAT/AMAJIN	19	11	8	-
Municipalities	33	4	29	-
Private	1	1	-	-
Total	**222**	**154**	**60**	**8**

Source: ENACAL, 2008a.

works. According to the 2008-2012 Institutional Development Plan, ENACAL intends to raise drinking water coverage form 77% to 88%; increase time of uninterrupted service from 15 to 22 hours per day; and elevate water production from 271.06 Mm^3/year (8.59 m^3/s) to 296.57 Mm^3/year (9.40 m^3/s) (ENACAL, 2008a).

5.3. Water Treatment for Use in Urban Areas

As already mentioned above, groundwater supplies 70% of total drinking water, while the remaining 30% comes from surface or subsurface water (FAO-CEPAL, 2009). This results from more than 86% of the population living in the Pacific watershed (20% of the territory) which hold only 6% surface water (Montenegro, 2009).

These demographic and hydrographic characteristics have led various governments to direct their attention towards strategies that exploit underground hydric resources, not only because the water collection and disinfection works are cheaper, but also because of the high quality of these waters. The situation has involved inconsistent technological development; while capability and experience in the exploitation of groundwater, such as well drilling and disinfection techniques, are more highly developed, technology for collection and purification of surface water has lagged behind. There are 17 water purification plants in Nicaragua: four rely on slow sand filtration, 12 on rapid sand filtration and one is a desalination plant. Most water purification plants in the country have low cost technology and rely on the hydraulic energy of the system. There are only three high technology plants which demand a considerable amount of energy to operate and are expensive to maintain; among them the inverse osmosis (desalination) plant stands out, although unfortunately it is currently disabled due to high operation and maintenance costs (ENACAL, 2008a). Most of the water purification plants in the country are found in the northern and central regions; the most important and largest ones are located in the cities of Ocotal, Juigalpa, Boaco and Camoapa. In the Atlantic region, the desalination plant collects water from Bluefields Bay to supply the city that bears the same name, involving high operation and maintenance costs. (ENACAL, 2008a).

Before water is delivered through distribution networks, it is disinfected by chlorination. In relation to the issues involved in water purification and disinfection, various non-governmental organizations, national universities and cooperation agencies have come up with community development projects that rely on the application of a variety of water treatment procedures such as filtration techniques, exposure to solar radiation and aeration, among others. 1,200,000 homes in Nicaragua receive water and sanitation services form Drinking Water and Sanitation Committees (Comités de Agua Potable y Saneamiento –CAPS; http://capsnicaragua.blogspot.com), rural community organizations which execute organization and operation practices to supply these services.

5.4. Current Situation and Coverage of Sewerage Services

In spite of the efforts of various national governments to improve sanitation, the situation continues to be poor. According to the 2005 census, only 25% of the population living in Nicaragua has access to a sewerage system, although this figure increases to 59% if the term "sanitation" is broadened to include the use of latrines and privies. Nevertheless, this continues to be deficient, considering that the country's population is greater than five million inhabitants (FAO-CEPAL, 2009).

Similar to drinking water, the gap in sanitation between urban and rural areas is significant: 43% of urban population has lavatories, while the figure drops to only 2.1% in rural areas. Within the rural population, most have access to latrines, although 30% have no access to any type of sanitation services at all (INEC, 2005).

This implies that a large percentage of individuals practice outdoor defecation, which is a threat to human health. In 2008 Nicaragua reported 21% outdoor defecation in rural areas, 4% in urban areas and 11% in the entire population (PCM, 2010).

Sewage services are only available to less than 42% of the population, with urban peripheries and rural areas mainly lacking the service (ENACAL, 2008a). This leads to inadequate disposal of grey water which flows through yards, streets, channels or ravines; a good part filters into the soil and the remaining part drains into a surface water body. According to ENACAL's 2008-2012 National Development Plan, 36 cities have sewerage systems, representing 20% of municipal and departmental capital cities found in the Pacific and Central regions of the country. However the issue becomes even more alarming knowing that most sewage systems have exceeded their useful life and they must be expanded, renovated and in some cases closed down and replaced.

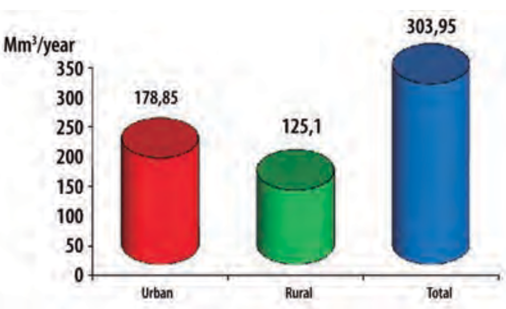
Sewage systems are made of cement piping with manholes built with bricks. They have main and secondary collectors and separate collection systems for rain and wastewaters. As a consequence of the age and poor management of the sewage system, it is in poor condition, and several branches are blocked and cut off due to accumulation of fats, solids and sediments from rivers (FAO-CEPAL, 2009). Storm sewer systems are less vast than sanitary sewers, which results in illegal connections between storm and sanitary sewers and limits proper functioning. During very heavy rains, water flowing through pipes exceeds their designed capacity and often leads to collapse of the sanitary sewage systems (FAO-CEPAL, 2009).

5.5. Volume of Wastewater Produced

Because official data on the volume of wastewater produced in Nicaragua are lacking, estimates for the volume of domestic wastewaters produced for the year 2010 have been based on the fact that wastewater production represents approximately 80% of clean water use. The results can be seen in FIG 18.

5.6. Coverage and Percentage Treated Wastewater

Thirty-six cities in Nicaragua have sanitary sewage systems of which only 27 have wastewater treatment plants; therefore only 38% of collected wastewaters are treated (SINIA-MARENA, 2009). It is important to note that although Nicaragua has 215 cities considered to be urban areas (Arguello, 2008), only 27 treat their wastewater, and thus only 12.5% of urban wastewaters are treated. Sanitary sewage that is not treated is discharged into bodies of surface waters (rivers and lakes), indiscriminately polluting hydric resources (FAO-CEPAL, 2009). In rural areas, the situation is even worse as there is no treatment of wastewaters whatsoever. This is a consequence of the sector's development policies which are focused on supplying water for human use, providing latrines and health education, leaving management of wastewater aside; thus waste or grey water flows along streets, avenues and riverbeds (FAO-CEPAL, 2009).



SOURCE: PERSONAL COMPILATION (CIRA/UNAN) BASED ON POPULATION PROJECTION (INEC, 2005) AND NTON DATA FOR CLEAN WATER SUPPLY (INAA, 1999).

FIG. 18. Estimate for the Current Production of Domestic Wastewater in the Country.

In 2008, total treated domestic wastewater was calculated at 44.6 mm^3/year (1.41 m^3/s). In early 2009, the largest water treatment plant in Central America began operating in Managua. It treats 66.6 mm^3/year (2.11 m^3/s), thus increasing the total volume of wastewater treated in the country (ENACAL, 2008). According to the latest figures presented by ENACAL in its IV Report on the State of the Environment, wastewater treatment increased from 17% in 2006, to 31.4% in 2008.

Wastewaters that flow through sanitary systems consist of grey water, raw sewage and in the rainy season, rainwater from certain homes that have an illegal connection to the system. This situation results in a high organic composition of domestic wastewaters, as well as a high concentration of nutrients such as nitrogen and phosphorus, in addition to abundant pathogens, sediments and detritus.

5.7. Wastewater Treatment Systems

Traditionally in Nicaragua, stabilization ponds have been considered an alternative to wastewater treatment. Of the 27 treatment plants in the country, 13 use this method to treat sewage. In addition, the Managua plant has an anaerobic reactor followed by facultative lagoons and a maturation pond, six Imhoff tanks with ascending flow anaerobic filters, five septic tanks with anaerobic ascending flow filters, a septic tank system with anaerobic ascending filters, a septic tank system with infiltration ditch and a system made of primary sedimentation, biological trickle filter and secondary sedimentation (FAO-CEPAL, 2009).

Systems operating properly are efficient at removing organic load and suspended solids, but inefficient at removing nutrients and pathogens. Most domestic wastewater treatment systems however, are in an advanced state of deterioration due to lack of maintenance and poor operation as well as design shortcomings that range from inadequate sizing to the absence of preliminary works for the initial treatment of inflows, leading to serious environmental problems for the bodies of water that receive the treated effluent. An example of this is Lake Masaya which suffers a high degree of eutrophication because it directly receives the effluent from the oxidation pond of the Masaya municipality (FAO-CEPAL, 2009).

5.8. Applied Technology for the Treatment of Wastewaters

Presently, all existing treatment plants for domestic wastewater operate by means of physical, biological, aerobic, anaerobic processes or in combination with hydraulic systems. Treatment systems found in middle to high-class urban areas, which have sprung up in recent decades, use conventional technology. The most common among these systems are compact activated sludge plants, which require electricity for their operation.

With respect to industries, treatment technology has focused on conventional options: activated sludge, biological filters, compact treatment plants, etc. In these cases, technology depends greatly on the characteristics or components of the effluent.

5.9. Reuse of Water

In Nicaragua, the reuse of treated water is an uncommon practice, possibly because treatment systems in the country have been shown to be inefficient to remove pathogens and this hinders the use of treated waters for a variety of activities such as irrigation, field application, cleaning, and aquaculture, among others. From 2000-2002 the effluents of only six treatment plants were reused in agriculture, specifically forestry plantations and tall-growing crops (CEPIS-OPS, 2002).

The percentage of treated wastewater that is reused is currently unknown, but most often treated effluents are poured into bodies of surface waters such as lakes and rivers, and a small percentage is used in seepage pits, a practice used in certain compact plant treatment systems found in urban areas.

5.10. Present Situation of Distribution and Sanitation Networks

Considering that water supply systems are designed for a period of 25 years, most drinking water distribution networks in urban areas in Nicaragua are obsolete. The fact that their useful life is over, in addition to the poor maintenance given to pipes and pumping equipment, have resulted in serious problems regarding water leaking out during distribution, mainly due to rusted or broken pipes. Other aggravating circumstances include the connections made by spontaneous human settlements in which pipes lacking adequate technical specifications are used thus increasing the frequency and amount of water leakage in the networks. A considerable amount of investment is needed to restore and extend the existing waterworks systems.

As to sanitary sewage networks, the situation is even more precarious; as mentioned previously, 36 of the 215 cities considered to be urban areas have sewage systems, and the coverage is only 50%. The problem however becomes acute when considering the state of obsolescence in which most of the existing sewage systems are found in, in addition to the inadequate use the systems are given by people that pour domestic rainwater into them and in some cases, even solid wastes. This situation, which is evident in the constant blockage issues and spilling of wastewaters in various manholes on streets and avenues and the noxious smells and runoff of grey water, has placed the sanitation system on the verge of collapse (ENACAL, 2008).

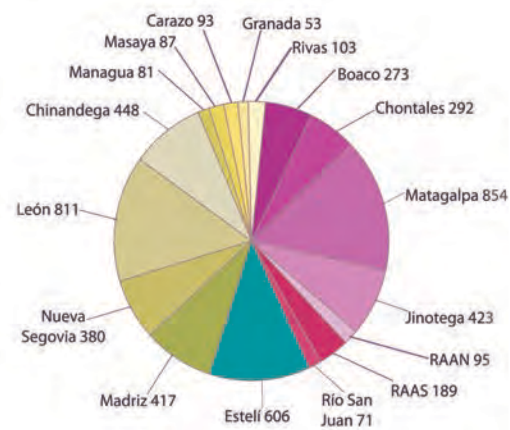
Such a dramatic situation demands greater investment in the sector to allow restoring, extension and maintenance of the sanitation networks, together with campaigns to increase environmental awareness and education that will lead to better service, coverage and function.

5.11. Drinking Water and Sanitation in Rural Areas

In rural areas, drinking water services are supplied by ENACAL, municipalities and CAPS. INAA, who regulates this sector, reported rural drinking water coverage of 56% in 2006 (ENACAL, 2008).

In 2008 it was estimated that 5,276 rural aqueduct systems supplied the same number of small rural communities (ENACAL, 2008). The distribution of these water supply systems per department is shown in FIG. 19.

The departments of Matagalpa, León, Estelí and Jinotega have most rural waterworks; in contrast, the North Atlantic regions have the least amount of works and are thus the most depressed area regarding the drinking water sector. It is estimated that half of the rural population in the Pacific region of Nicaragua has no access to drinking water in their homes and is thus forced to supply themselves through communal and individual wells, rainwater or surface water from rivers, lagoons or shallow reservoirs used for livestock watering. From a sanitary viewpoint, this represents an important health risk. Nevertheless, the situation is even more serious in the Atlantic region because 80% of the population has no direct access to drinking water at all.



SOURCE: PERSONAL COMPILATION (CIRA/UNAN) WITH DATA PUBLISHED BY ENACAL, 2008

FIG. 19. Distribution of Rural Aqueducts per Department;

Disperse communities present the greatest supply challenges as people often have to walk several kilometers to find a source of water. The supply system is conditioned by how long the network has existed, plus the yield and building of wells. An additional factor that hinders access to the resource are new and illegal connections to the system by middle to high-class condominiums and developments which lack their own wells and result in pressure loss in the supply networks.

Supply in rural areas is covered by small systems, of which the most commonly used are hand-dug wells (PEM –pozo excavado a mano), drilled wells (PP -pozo perforado), mini-aqueducts by electric pumping (MABE¬ –mini acueductos por bombeo eléctrico), mini-aqueducts by gravity (MAG –mini acueductos por gravedad), collection from springs (CM -captaciones de manantial). Up to the year 2002, there had been 4, 886 works registered for all the systems mentioned (ENACAL, 2005).

Unfortunately, supply in rural aqueducts in most cases is not continuous, quantity is rationed and quality is far from optimum as the result of a lack of monitoring systems. In general, most rural drinking water supply systems have been built with external aid and insufficient precaution was taken to ensure their sustainability. Likewise, there has been no maintenance and follow up for the works, thus many are non-operating and communities are without service.

According to the most recent population census (INEC, 2005), 84.8% has some kind of sanitary service, latrines being the most common; 15.4% has no service whatsoever; 43% urban population has toilets while this is so for only 2.1% of rural areas. Sanitary sewer system coverage is less than 50% and grey waters are directly disposed of in yards, streets, streams or ravines eventually reaching bodies of surface water or filter into the soil. In Nicaragua, only 56% municipalities have a regular garbage collection service, covering an average of 49% nationally. Most municipalities have open air landfills and only 13% de of these comply with the technical and sanitary requirements to operate (MARENA, 2005b).

Domestic wastewaters in rural areas go untreated, although there have been isolated experiences with the use of the technologies applied in urban areas. These are individual treatment systems that deal with grey waters; they use biofilters or filter beds by way of artificial wetlands. Another common practice is the use of septic tanks that lack soil waterproofing and thus become potential sources of pollution.

Composting latrines have been used to treat sewage, although unsuccessfully for cultural reasons. Garbage collection services are almost non-existent in rural areas and people rely on burning or burying trash or they dispose of it illegally in streams, brooks, river beds, lakeshores and the ocean. During the season of heavy rains, currents carry solid wastes into bodies of surface waters like lakes, lagoons and even the ocean, causing serious impact on aquatic ecosystems.

6. Climate Change

Various studies (MARENA, 2005a, 2007, 2008a, b, c, 2009; González, 2006; MARENA, PNUD, 2000; CATHALAC, PNUD, GEF, 2008; CEPAL, GTZ, 2009; CEPAL, 1999) point at the main effects of climate change in Nicaragua:

1) Increase in atmospheric temperature and change in rain patterns and amount of precipitation, that produce dry periods in specific areas of the country due to a decrease in groundwater level and runoff in the surface water system;
2) Increase in natural threats caused by hurricanes, intense precipitation, flooding, frequency and length of droughts, fire, and heat waves, that affect

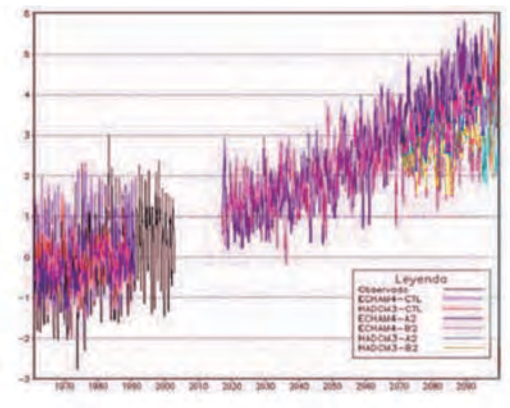
water resources both in quantity as well as quality, and

3) Increase in sea level, especially along the Atlantic coast where flood-prone areas are expected to increase as well as erosion along the coasts, and saline intrusion.

In addition, these studies emphasize that the negative impact caused by climate change must be added to that produced by man-made environmental degradation of hydrographic basins that results from inadequate water use, the relation between water distribution and demand, as well as economic activities. All of these factors have made an impact on the amount of water and its quality.

6.1. Changes in Temperature and Rain Patterns

According to temperature projections and as a consequence of climate change (CATHALAC, UNPD, GEF, 2008), an increase between 1°C and 2°C is expected in the first decades of this century (2020-50), and increases of up to 3°C and 4°C are expected at the end of this period. Warming is expected to be less on the Caribbean coast than in the Pacific, specifically between Guatemala and the Mosquita region found between Honduras and Nicaragua. As to rainfall, a decrease is expected in most of Central America, with greater reductions in Nicaragua, in the order of -40% (MARENA, 2009). The "Segunda Comunicación Nacional sobre Cambio Climático" (Second National Report on Climate Change) and the use of the Regional Modeling System PRECIS, obtained more precise results for the country. These projections show a warmer climate (FIG. 20), in which the range between the maximum and minimum temperatures narrows in the Pacific region.



SOURCE: MARENA, 2009.

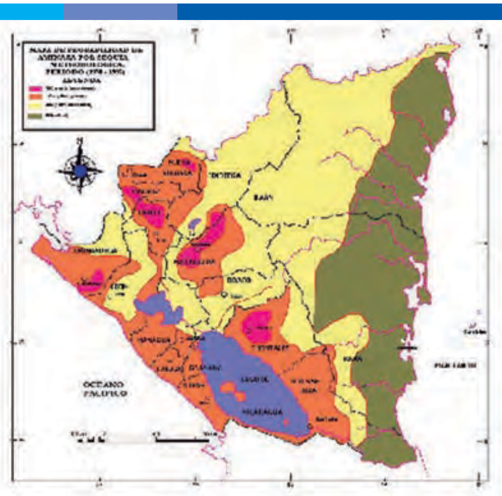
FIG. 20. Projections for Monthly Average Surface Atmospheric Temperatures in Nicaragua (projections for Nicaragua on application of the Regional Modeling System PRECIS (Providing Regional Climates for Impact Studies).

Increases in average annual temperatures could cause important impact on a variety of production sectors and human activities as they greatly affect production capacity for many crops, determine human health and well-being, and could, to a certain extent limit adaptation of living things in the national territory. Regarding precipitation, a decrease can be observed in the Atlantic region, as well as a possible increase in the southern part of Nicaragua, in the area it shares with Costa Rica and Panamá. According to Síntesis regional: Fomento de las capacidades para la Etapa II de adaptación al cambio climático en Centroamérica, México y Cuba (Regional Summary: Promotion of Abilities for Stage II Adaptation to Climate Change in Central America, Mexico and Cuba), "the increase in average temperature in the coming decades could be greater in subtropical latitudes. This rise could be greater in Central America, along the Pacific coast, near Guatemala, El Salvador and Nicaragua". The Nicaraguan Pacific has been identified as the region most vulnerable to water scarcity, even under an optimistic scenario, because of the drop in rainfall expected by the year 2030 and the high vulnerability associated to an increasing population rate, intensive agricultural practices and environmental decline. The North-Central region presents moderate vulnerability.

As to water quality, greater deterioration is expected as a consequence of pollution by agricultural chemicals used in more intensive agricultural practices and the discharge of untreated liquid wastes (MARENA, 2001). In such a scenario, the water table of the Pacific basin is considered to be highly vulnerable as it is already under pressure because of intensive farming, industry, lack of wastewater treatment and saline intrusion in coastal areas. The country's Central region is considered at a mid-level risk because of agriculture and deforestation. In terms of variations in rainfall, a reduction is expected for the months of July and August, corresponding precisely to the dry season (MARENA, 2009). This situation, together with a the need to increase irrigation areas, population increase and a large amount of industrial and agricultural activities, will cause a fall in water tables and thus a greater demand for pumping water. The various scenarios for the modeling of aquifer recharge in dry years indicate that vulnerability is high, as this factor shows a 50% fall, leading to a fall in aquifer level below what is safe for exploitation. This is an extremely important risk indicator for the future, especially under situations of prolonged drought associated to climate change (MARENA, 2005a). On the other hand, as stated in Section IV.6.2, low water tables, along with a fall in volume in tributary rivers, promote greater groundwater pollution. Likewise, the León-Chinandega aquifer, found in Basin N° 64 is predicted to suffer water scarcity, in terms of the existing infrastructure as from 2015.

This situation causes concern because, as noted in Section IV.6.2, the aquifer is the main source of water for all uses (domestic, irrigation, industrial and municipal). In addition, it is expected that the poorest rural communities – particularly small-scale producers- will be the most affected in these circumstances (MARENA, 2008a), as they depend on shallow individual wells. As a result of water scarcity, people will be more vulnerable to water-borne diseases and to malnutrition as there will also be a lack of food, a decrease in grain production and the proliferation on pests. According to studies by INETER (FIG. 21), the areas most exposed to drought are the Pacific West (Chinandega) and certain municipalities in the Central regions (Chontales). In the Northern region, the most affected area is found between the mountains of Dipilto, Jalapa and Isabelia and the de Tepesomoto range (INETER, 2000).

In conditions of a modified climate, these areas would receive less that 500mm precipitation per year, and suffer important consequences in agriculture and livestock activities. Most of the Central and South Pacific might go from having a rainfall of 1,400-1,800 mm/year to 800-1 000 mm/year. As a result, the arid areas in Nicaragua would grow, and municipalities currently considered as dry would become even drier by the year 2100 (INETER, Dirección General de Meteorología, 1997).



SOURCE: INETER, 1994.

FIG. 21. Map of Areas Vulnerable to Drought in Nicaragua;

6.2. Extreme Events

Extreme events, i.e. drought and flooding, affect the poorer and most vulnerable sectors of the population the most. They also upset governmental efforts for development and cause the environment to deteriorate; modifying the conditions water resources are in. During the last decade there has been an increase in frequency and magnitude of El Niño and La Niña, which are associated to droughts and flooding respectively. On one hand, La Niña is related to tropical storms and hurricanes and brings about heavy rainfall. In the recent past, seven strong hurricanes have caused floods and serious economic and social damage in Nicaragua and neighboring countries. These hurricanes are Fifí (1974), Alleta (1982), Joan (1988), César (1996), Mitch (1998), Keith (2000) and Félix (2006). Nicaragua's Caribbean coast is in the pathway Basin N° 3 hurricanes (Gulf of Mexico, Caribbean Sea and the Atlantic Ocean). On average, there are 9.6 tropical storms per year. In addition, there is a 6% probability of a direct hit by a hurricane in the Bluefields area, and a 36% in the "Cabo Gracias a Dios" area located in Northern Nicaragua on the border with Honduras. This implies a high vulnerability to extreme events in the Autonomous Regions of the North and South Atlantic of Nicaragua (MARENA, 2009). Although it is the region with the most water resources, the health risk is high because of its low human development index (the percentage population without water services for the North Atlantic Autonomous Region is 64%, and for the South Atlantic Autonomous Region, 89%) and the great number of users lacking drinking water services.

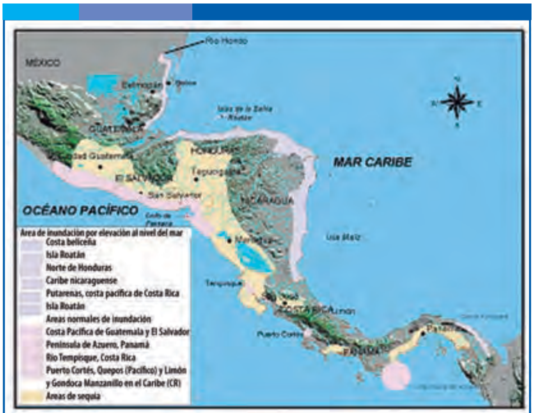
Likewise, El Niño produces warm events and drought, as those occurring in the years 1972, 1976-77, 1991, 1992, 1994 and 1997 (MARENA, 2008b). In late drought conditions, (August to December), there is an increase in probability of forest fires which destroys soil structure and fertility and makes soil more susceptible to water erosion. From 2004 to 2007, between 1,801 and 4,160 hot spots have been registered in the entire national territory (SINIA, 2008) concentrated in areas dedicated to farming. The Atlantic and San Juan River areas are the most affected by forest fires (MARENA, 2001).

Floods are caused by the accumulation of surface runoff from strong precipitation on rivers that run over into the flooding plains. The areas in Nicaragua most susceptible to flooding are located in the Atlantic regions and, to a lesser degree in the lowlands of the Nicaraguan Depression, and the shores of Lakes Xolotlán and Cocibolca in the Pacific region (MARENA, 2008b). Torrential rains can also affect the infrastructure used to collect and distribute drinking water, leading to water-borne diarrheic diseases. The impact of hurricanes, such as hurricane Mitch, produce contamination of surface water and wells in flood-prone areas that are also affected by massive dragging of soils that have accumulated pesticides (CIRA/UNAN, 1999a). Flood waters can also carry all kinds of contaminants, which affect highly permeable and shallow aquifers, as occurred in León-Chinandega on the passage of hurricane Mitch. The rural sector is highly vulnerable to these extreme events as these communities rely on shallow community wells that lack sanitary seals and any kind of protective measure, as a source of domestic water.

6.3. Rise in Sea Level

It has been calculated that sea levels could rise up to 35 cm in the present century (IPCC, 2007). FIG. 22, "Flood Areas due to Sea Level Rises" show that Nicaragua's Caribbean coast would be the most affected, consequently becoming more prone to flooding, coastal erosion and saline intrusion. In addition, the wetland systems, which cover ~90% of the coastline, would be affected as well.

According to Table 28, five municipalities are at risk of potential salinization of water sources, with a total population of 145,328 inhabitants representing 17% of the population in the Caribbean region. The rise in sea level, together with the high vulnerability to hurricanes, justifies the concern for "more intense storm surges that affect larger areas of coasts" (MARENA, 2009).



SOURCE: SICA, MARCO REGIONAL DE ADAPTACIÓN AL CAMBIO CLIMÁTICO PARA CENTROAMÉRICA.

FIG. 22. Flood Areas due to Sea Level Rises.

Table 28. Estimate of the Population Supplied by Coastal Aquifers on the Nicaraguan Atlantic coast.

Cities supplied by coastal aquifers	Population estimate for 2008
Puerto Cabezas	68,783
Prinzapolka	16,741
Laguna de Perlas	11,098
Bluefields	47,347
San Juan del Norte	1,359
Total	**145,328**

Source: Personal compilation from population data in INEC census, 2005.

The consequences of climate change are a latent threat to human development in Nicaragua. There is a vicious circle regarding poverty that involves "current rural poverty, continuous breakdown of renewable natural resources and vulnerability in the face of climate change". It has been determined that 65% of Nicaraguan households are poor (Banco Central, 2008), with daily incomes of less than two dollars. It is urgent to plan how adaptation to climate change is to occur in order to avoid worsening of the expected impact (PNUD, 2007-2008). The wealth that hydric resources represent in Nicaragua could become an important cornerstone for the nation's development; therefore, it is extremely urgent to protect and manage these resources comprehensively based on the potential impact caused by climate change.

7. Water and Health

The water and sanitation crisis above all affects the poorest population; nearly two out of every three people in the world who lack access to clean water survive on less than two dollars a day as well as more than 660 million people who lack sanitation. In Nicaragua, 75.8% of the country's population lives on less than two dollars a day (ENACAL, 2007).

Furthermore, the lack of sanitation is strongly associated to water pollution by pathogens and chemical toxins and results in poor water quality leading to a series of diseases and social issues associated to poor quality of life of the population involved. Contamination by human activities directly affects aquatic ecosystems and human health as it is the cause of diseases that have serious effects on health and the quality of human life.

These so-called water-borne illnesses, linked to the deaths of millions of children every year, are produced by enteropathogens and mainly affect the intestinal tract with diarrhea as their most common symptom. Contaminated water and lack of sanitation are considered to be the second greatest cause of death worldwide (UNPD, 2006); in the year 2006 there were 144,000 recorded deaths caused by acute diarrheic diseases in Nicaragua (EDA) (ENACAL, 2007). In addition Nicaragua suffers from outbreaks of leptospirosis during the rainy season because water is contaminated with urine of Leptospira-infected rodents (MINSA, 2003).

Another important issue is chronic disease related to water contaminated by agro-chemicals, mainly organochlorines (Álvarez Castillo, 1994; Carvalho, 2002; Briemberg, J. 1994). Likewise, there are diseases caused by the contamination of water resources by heavy metals such as mercury and arsenic (Altamirano et al., 2009; Jimenez et al., 2009).

Regarding the link between water availability and cases of acute and persistent diarrhea, it is worth noting that in the three years studied, the departments with the lowest drinking water production show a greater morbidity rate by acute and persistent diarrhea than the national. Every one of the departments with a rate similar or above the national morbidity rate for acute and persistent diarrhea are also those with serious problems concerning water supply according to ENACAL and those with scarce access to drinking water and sanitary services (ENDESA, 2007). Table 29 shows the relation that exists between safe and potable water and the incidence of acute and persistent diarrhea throughout several years.

In the western part of the country, the pollution by organochlorinated pesticides of soil, water and sediments has been widely documented (Montenegro et al., 2009; Montenegro et al., 2007; Carvalho et al., 2002). In this area, xenobiotics have been detected in blood,

Table 29. Percent Production of Clean Water per Department and Morbidity Rates by Acute and Persistent Diarrhea

Department	Annual Production of Clean Water (%)	Morbidity rate by acute and persistent diarrhea (2005)	Morbidity rate by acute and persistent diarrhea (2006)	Morbidity rate by acute and persistent diarrhea (2007)
Boaco	0.9	419.24	360.69	466.03
Carazo	4.0	428.75	396.63	454.12
Chinandega	5.9	195.24	18.6	188.19
Chontales	1.8	243.73	205.4	328.99
Estelí	3.2	506.58	407.75	407.71
Granada	4.3	306.5	199.48	217.91
Jinotega	0.8	355.6	330.97	316.42
León	8.0	240.72	155.93	168.7
Madriz	0.7	437.52	403.76	449.72
Managua	56.7	347.19	262.92	361.49
Masaya	4.6	268.66	219.11	277.26
Matagalpa	3.3	518.49	438.86	448.61
Nva. Segovia	1.8	360.22	315.3	275.46
Río San Juan	0.2	581.81	444.6	442.96
Rivas	2.2	294.66	222.8	245.63
RAAN	0.2	662.49	888.12	919.29
RAAS	0.7	863.10	704.79	863.97
Total	100.0	370.68	315.16	364.1

Rate x 10 000 inhabitants
Source: ENACAL, 2007 y OPS, 1996.

umbilical cord and human milk (Cruz Granja, 1995; Lacayo, 1995; CIRA/UNAN, 1997), while there is also a high prevalence of chronic renal disease and patients with chronic renal failure (Marín, J. 2007), apart from sterility, cancer and congenital malformations which very probably are related to the nephrotoxic, carcinogenic, mutagenic and teratogenic effects of these compounds.

As regards to arsenic, natural contamination with this element has been detected in Nicaragua in water for human use in the following regions: Northwestern (Villanueva, Santa Rosa del Peñón), North central (Madriz, Nueva Segovia), Central (Valle de Sébaco) and in the Department of Chontales (La Libertad, locality of Kimuna) (Altamirano and Bundschuh, 2009). Conservative estimates have determined that approximately 55,700 people in Nicaragua are drinking arsenic-contaminated water (UNICEF-ASDI, 2004).

8. Legal Framework

The first regulations related to water resources in Nicaragua were established in the Civil Code, the legal instrument with a vision, scope and spirit dating from 1904. It established a privatizing influence on natural resources and determined that water is subject to special regulations, as stated in Article 723: "Everything regarding public waters, particularly those that are navigable and fluctuating, rainwater, channels, private aqueducts and other works concerning the use of water; and finally to all plant substances, whether land or aquatic, are subject to special by-laws" (Official Journal, 1904). More than 50 years went by before the first law to try to regulate natural resources, called "Ley

General Sobre Explotación de las Riquezas Naturales" (General Law for the Exploitation of Natural Resources) (1958) (La Gaceta, N° 83, April, 1958) was enacted; nevertheless, once again water was left out of the legal framework. Because of the absence of a clearly-defined legal framework, the most widely applied norms were those found in the Civil Code which recognizes the private property of water and in the name of individual rights has allowed the contamination of water resources in the entire country.

Nearly 100 years passed before the first laws that intended to protect water resources in a comprehensive manner were passed by means of the General Law for the Environment and Natural Resources (Ley General del Medio Ambiente y los Recursos Naturales [Ley 217]) (La Gaceta, 1996), promulgated and put into effect in 1996. For the first time, the law modified the concepts relating to privatization and individual rights found in previous laws, and established legal consistency with the Constitutional provision found in Article 102 which states: "Natural resources are national patrimony.

The preservation of the environment, as well as the conservation, development and exploitation of natural resources is a concern of the State". Along these lines, Law 217 states in Article 72: "Water, in all of its states, is of public domain. In addition, the State owns the beaches of oceans, rivers and lakes; riverbeds and basins of natural water deposits; salinitrous lands, firm ground found up to thirty meters beyond the maximum waterline or the permanent banks of rivers and lakes, and the stratum or deposits of groundwaters".

Law 217 contains 22 Articles dealing with various aspects with regards to water resources; however, they have not been applied on account of the lack of an institution in charge of implementing it and protecting the resource. The National Policy for Water Resources (La Gaceta, 2001) relies on management per watershed as the foundation for the integrated governance of water resources in Nicaragua. It also determines the importance of water as national wealth of public domain to satisfy the basic needs of the population, respecting principles of social and gender equity. The policy foresees the impact of climate change when it states in Article 2: "The objectives of the National Policy for Water Resources are the use and integrated management of hydric resources in line with the social and economic requirements of development and in accordance with the capacity of ecosystems, in the benefit of present and future generations, as well as to prevent natural disasters caused by extreme hydrological events".

The legislative history of water regulation reaches its peak in September of 2007, when the first law to regulate hydric resources is approved and passed becoming the first valid legal instrument for the sustainable management of water. This law established a comprehensive regulatory framework in line with the National Policy for the administration, conservation, development, use, sustainable and equitable exploitation of hydric resources in the country, as well as the preservation of their quantity and quality. (C. García, President of the Environmental Commission of the National Assembly). The General Law for National Waters (Law 620) and its norms make an emphasis on the integrated management of water based on the country's hydrographic and hydrogeologic basins, sub-basins and micro-basins. The most important component of the Law is the creation of the National Water Authority (ANA - Autoridad Nacional del Agua) in Art. 24, which states: "The National Water Authority (ANA) is hereby created and will be the decentralized organ of the Executive Power as regards to water, with its own legal status, administrative and financial autonomy and with technical-regulatory, technical-operational, control and follow-up capacities to exercise the nationwide administration and management of water resources, according to the present Law and its norms".

ANA (Art. 25) is responsible for putting the creation of basin agencies to the consideration of the National Council for Water Resources (CNRH - Consejo Nacional de Recursos Hídricos). In addition, ANA also organizes and coordinates the Information System for Hydric Resources, which determines the availability of national waters regarding quantity and quality, and establishes the inventory of water uses and users. This system covers geographic, meteorologic, hydrologic and hydrogeologic information and includes the handling of data bases, operation and maintenance of networks and circulation of the information obtained (La Gaceta, 2007b). Another important aspect of Law 620 is that it recognizes Lake Cocibolca, the largest in Central America and the largest tropical Lake in the American continent, as a national reservoir of drinking water as a way to stop the pollution of its waters. As a result, the "Commission for the Sustainable Development of Lake Cocibolca and San Juan River Basin" (Gaceta, 2007a) was created, and its function is to make, approve and follow the Plan for Action Territorial Planning for Basin Management (Montenegro, 2009).

On the other hand it is important to add that the Plans for Municipal Development include an addition element for water management, as it establishes in Art. 6 of the Law for Municipalities (Law 40) that "municipal governments have competence in all matters that have incidence on socio-economic development, conservation of the environment and natural resources within their territorial circumscription".

Likewise, the General Law for the Environment and Natural Resources of Nicaragua (Art. 83) states that autonomous governments and municipalities can determine the maximum amounts of water to be extracted within their jurisdiction.

In 2010, the National Water Authority was established and is currently developing the foundations to apply Law 620.

9. References

1. Agenda 21-Nicaragua. Aspectos del desarrollo sostenible referentes a los recursos naturales en Nicaragua. http://www.un.org/esa/agenda21/natlinfo/countr/nicara/natur.htm#toxic
2. Altamirano, M. y Bundschuh, J. (2009). Natural arsenic groundwater contamination of the sedimentary aquifers of southwestern Sébaco Valley, Nicaragua. Geoquímica del arsénico en América Latina.
3. Altamirano, M. (2005). Distribución de la contaminación natural por

arsénico en las aguas subterráneas de la subcuenca suroeste del Valle de Sébaco, Matagalpa-Nicaragua.
4. http://www.cira-unan.edu.ni/media/documentos/MaxAltamirano.pdf.
5. Álvarez Castillo, José Antonio (1994). Niveis de contaminacao das águas da Bacía do rio Atoya por resíduos de pesticidas organoclorados e organofosforados aplicado na cultura do algodão Bacía de rio Atoya Chinandega, Nicaragua America Central. Tesis de Maestría (Universidad Federal do Paraná Brasilia).
6. Andre, L., Rosen, K., Torstendahl, J. (1997). Minor field study of mercury and lead pollution from gold refining in central Nicaragua. Department of Environmental Engineering, Lulea University of Technology, Lulea.
7. Argüello , O. (2008). Revisión y actualización de la estrategia del sector de agua potable y saneamiento, 2008-2015, Nicaragua/Informe final. Managua, julio de 2008.
8. Banco Mundial (2001). Recurso hídrico per cápita por año de los países centroamericanos y otros países de referencia. www.aguayclima.com/agua/inicio.htm
9. BCN (2009). Banco Central de Nicaragua. Nicaragua en cifras. http://www.bcn.gob.ni/publicaciones/nicaraguacifras/Nicaragua%20en%20cifras%202007%20WEB.pdf
10. BCN (2008). Banco Central de Nicaragua. Anuario de Estadísticas Económicas 2001-2008. http://www.bcn.gob.ni/publicaciones/anuario/Anuario%20estadistico%202008.pdf
11. Briemberg, J. (1994). An investigation of pesticide contamination of groundwater sources for urban water distribution systems in the Pacific Region of Nicaragua. Final Report 3, CIDA Awards for Canadians.
12. Calderón, H. (2003). Numerical modeling of the groundwater flow system in a sub-basin of the Leon-Chinandega aquifer, Nicaragua. MSc Thesis. University of Calgary, Calgary, Alberta.
13. CATHALAC, PNUD, GEF (2008). Síntesis regional: Fomento de las capacidades para la Etapa II de adaptación al cambio climático en Centroamérica, México y Cuba. Edición final [E. Sempris, M. Chiurliza, Joel Pérez, R. Carrillo y M. Tuñon (eds.)].
14. CCO (2001). Cuerpo de Ingenieros de los Estados Unidos de América, Distrito de Mobile y Centro de Ingeniería Topográfica Regionalización. Biofísica de tres regiones del Pacífico de Nicaragua. http://www.sam.usace.army.mil/en/wra/Nicaragua/WRA%20SPANISH.pdf
15. CAPS Nicaragua (2009). http://capsnicaragua.blogspot.com
16. Carvalho, Fernando P., Villeneuve, J. P., Cattini, Chantal, Tolosa, Inmaculada, Montenegro Guillén, S., Lacayo, M. y Cruz, A. (2002). Ecological risk assessment of pesticide residues in coastal lagoons of Nicaragua. The Royal Society of Chemistry, Journal of Environmental Monitoring, 4, 778/787.
17. Castillo Hernández, E., Calderón Palma, H., Delgado Quezada, V.,

Flores Meza, Y. y Salvatierra, T. (2006). Situación de los recursos hídricos en Nicaragua. Boletín Geológico y Minero. (Situation of Water Resources in Nicaragua). Instituto Geológico y Minero de España, 117 (1):127-146.
18. Catastro e Inventario de Recursos Naturales (1973). Ministerio de Economía, Industria y Comercio.
19. Centro Humboldt (2001). Caracterización hidrogeológica, hidroquímica, bacteriológica y de plaguicidas en las aguas subterráneas del municipio de Posoltega. Managua, Nicaragua.
20. CEPAL, GTZ (2009). Cambio climático y desarrollo en América Latina y el Caribe: una reseña. http://www.eclac.cl/dmaah/noticias/paginas/6/34886/libro-cc.pdf
21. CEPAL (1999). Nicaragua: evaluación de los daños ocasionados por el huracán Mitch, 1998. Sus implicaciones para el desarrollo económico y social y el medio ambiente.
22. CEPIS-OPS (2002). Centro Panamericano de Ingeniería Sanitaria y Ciencias. Tratamiento y uso de aguas residuales en América Latina, Inventario regional del manejo de las aguas residuales. Convenio IDRC-CEPIS 2000-2002.
23. CIA, The World Factbook. https://cia.gov/library/publications/the-world-factbook
24. CIRA/IAEA (1999). Proyecto ARCAL XXXI. Caracterización de los acuíferos para la gestión sustentable de los recursos hídricos subterráneos en áreas urbanas. Informe de Nicaragua: Estudio Isotópico y de la Contaminación del Acuífero León-Chinandega, Nicaragua. Informe final.
25. CIRA/UNAN (2009). Centro para la Investigación en Recursos Acuáticos (Informe final de la Primera Campaña de Muestreo, Proyecto "Evaluación del Impacto de los Lixiviados del Basurero de la Ciudad de Managua, La Chureca, a las Aguas del Lago Xolotlán, al Acuífero Afectado y a la Laguna Acahualinca". CIRA/UNAN, Managua.
26. CIRA/UNAN (2008). Centro para la Investigación en Recursos Acuáticos. Informe final de Evaluación y monitoreo de la calidad del agua del Lago de Managua, Proyecto de apoyo a la ejecución del Programa de Saneamiento Ambiente del Lago y la Ciudad de Managua, Contrato de Préstamo BID 1060/SF-NI.ENACAL e INETER.
27. CIRA/UNAN, 2007. Análisis de la relación entre las presiones antropogénicas y el estado de la contaminación del Lago Cocibolca de Nicaragua. Integración de datos biológicos, físicos y químicos con datos geoespaciales e información de la cuenca hidrográfica del Lago Cocibolca. CIRA/UNAN–Fundación Ciudad del Saber.
28. CIRA/UNAN (1997). Plaguicidas organoclorados en sangre de madres del Departamento de Chinandega, Cuadra Leal, J., Cruz Granja, A. y Lacayo, M. Informe.
29. CIRA/UNAN (1999a). Centro para la Investigación en Recursos Acuáticos.

Diagnóstico de la calidad toxicológica de las aguas y suelos y calidad bacteriológica de las aguas del municipio de Posoltega. Managua, Nicaragua.
30. CIRA/UNAN (1999b). Centro para la Investigación en Recursos Acuáticos. Proyecto ARCAL XXXI. Caracterización de los acuíferos para la gestión sustentable de los recursos hídricos subterráneos en áreas urbanas. Informe Nicaragua. Estudio isotópico y de la contaminación del acuífero León-Chinandega. Managua, Nicaragua.
31. CIRA/MEL/DIPS, 1996-1998. Fate, Cycling and Environmental Effects of Agrochemical Residues from Cotton Culture in Coastal Lagoon Environments of Nicaragua. First year, Second year, Third year, and Final Reports.
32. CONAGAN (2009). Comisión Nacional Ganadera de Nicaragua. Comunicación personal con el Gerente General de CONAGAN, Dr. René Blandón.
33. CONAGUA y WWC (2006). Comisión Nacional de Agua y World Water Council, Datos de extracción de agua en Centroamérica. Presentado en el Foro Mundial del Agua México, 2006.
34. Cruz Granja, Adela (1995). Pesticidas organoclorados na gordura corporal de mulheres Nicaraguenses. Tesis de Maestria Universidad de Brasilia.
35. Delgado, V. (2003). Groundwater Flow System and Water Quality in a Coastal Plain Aquifer in Northwestern Nicaragua. M.Sc Thesis. University of Calgary, Calgary, Alberta.
36. ENACAL (2008a). Empresa Nicaragüense de Acueductos y Alcantarillados Sanitarios. Plan de Desarrollo Institucional 2008-2012: Estrategia sectorial de agua propuesta por ENACAL, diciembre de 2008. Managua. http://www.enacal.com.ni/media/imgs/informacion/LIBRO%20ENACAL%20CAMBIO%20ENERO-05.pdf
37. ENACAL (2008b). Empresa Nicaragüense de Acueductos y Alcantarillados Sanitarios. Revista. Informe de Gestión 2008, diciembre de 2008. Managua. http://www.enacal.com.ni/media/imgs/informacion/LIBRO%20ENACAL%20CAMBIO%20ENERO-05.pdf
38. ENACAL (2007). Empresa Nicaragüense de Acueductos y Alcantarillados Sanitarios. ABC sobre el recurso agua y su situación en Nicaragua. Segunda edición. http://www.enacal.com.ni/media/imgs/informacion/ABCdelAgua1.pdf
39. ENACAL (2005). Empresa Nicaragüense de Acueductos y Alcantarillados Sanitarios. Efluentes industriales que se descargan al alcantarillado sanitario de Managua. Gerencia Ambiental. Unidad de Vertidos Industriales, agosto de 2005.
40. ENDESA (2007). Encuesta Nicaragüense de Demografía y Salud, 2006-2007. http://www.ops.org.ni/index.php?Itemid=34&func=fileinfo&id=524&option=com_remository
41. FAO-CEPAL (2009). Los recursos hídricos de Nicaragua. http://coin.fao.org/medias/fao-nic-

recursoshidricos-capal-pdf
42. FAO (1992). Food and Agriculture Organization of the United Nations. Estudio Subsectorial del Riego Privado. Vol. II de II (Anexo 4, 5, 6, 7).
43. FAO-Aquastat (2005). Groundwater to surface water renewal ratio calculated from total annual internally generated groundwater and surface water volumes in the Aquastat database. www.fao.org/ag/agl/aglw/aquastat/main/lvOct05
44. FAO-AQUASTAT (2003). Water Resources, Development and Management Service, Information System on Water and Agriculture, Land and Water, General Summary Latin America and the Caribbean. www.fao.org/AG/agl/aglw/aguastat/regions/lac/index3.stm
45. Fekete, B., Vörösmartz, C. y W. Grabs (2002). Global Composite Runoff Fields, CSRC. UNH. Deichmann, U., Gridded Population of the World. http://www.ciesin.org/datasets/gpw/globaldem.doc.html
46. Flores, S. (2005). Flujo de macronutrientes (fósforo y nitrógeno) del Subsistema Hidrológico Lago Cocibolca: Estimación de carga superficial en relación al uso del suelo. Centro para la Investigación en Recursos Acuáticos de Nicaragua de la Universidad Nacional Autónoma de Nicaragua (CIRA/UNAN). Managua, Nicaragua.
47. González, H. C. (2006). Identificación de bosques y sistemas agroforestales importantes proveedores de servicios ecosistémicos para el sector agua potable en Nicaragua. Tesis para optar al grado de Magíster Scientae en Agroforestería Tropical. CATIE, Turrialba, Costa Rica.
48. GWP-CA (2006). Asociación Mundial para el Agua, Capítulo Centroamérica. Situación de los Recursos Hídricos en Centroamérica: Hacia una Gestión Integrada / Ed. Virginia Reyes G., 3ª Ed., San José, C. R.
49. Hydrological Bulletin (1991). Limnology of Lake Xolotlán (Lake Managua), Nicaragua. Journal of the Netherlands Hydrobiological Society. Vol. 25(2), 1991.
50. IEA-MARENA (2001). Informe Estado del Ambiente en Nicaragua 2001.
51. INAA (1999). Instituto Nicaragüense de Acueductos y Alcantarillados (NTON 09003-99). Normas técnicas para el diseño de abastecimiento y potabilización del agua. Managua.
52. INEC (2006). Instituto Nacional de Estadísticas y Censos. Informe del VIII Censo de Población y IV de Vivienda, Censo 2005. Managua.
53. INEC (2005). Instituto Nacional de Estadísticas y Censos. Encuesta de Hogares para la Medición de Empleo. Informe general.
54. INEC (2005). Instituto Nacional de Estadísticas y Censos. Informe de VIII Censo Poblacional y IV de Viviendas, 2005-2006. Revista.
55. INEC (2003). Instituto Nacional de Estadísticas y Censos. Compendio Estadístico 2000-2002.
56. INETER (2006). Instituto Nicaragüense de Estudios Territoriales. Boletín Hidrogeológico.

57. INETER (2004). Proyecto de Mapificación Hidrogeológica e Hidrogeoquímica de la Región Central de Nicaragua.
58. INETER (2000). Estudios hidrológicos e hidrogeológicos en la región de Chinandega–León–Nagarote (acuífero de Occidente). Instituto Nicaragüense de Estudios Territoriales–Ministerio Agropecuario y Forestal (MAGFOR).
59. INETER, Instituto Nicaragüense de Estudios Territoriales. Datos sobre la hidrología de Nicaragua. http://www.ineter.gob.ni/Direcciones/Recursos%20Hidricos/index.html
60. INETER (1997). Dirección General de Meteorología. Perspectivas de las precipitaciones en Nicaragua ante un evento ENOS, Documento técnico. Gutiérrez, M., INETER.
61. INETER/OIEA (1997). Estudio hidrogeológico del acuífero de Occidente. OIEA-INETER. NIC/8/009. Informe interno.
62. INETER (1994). Clasificación de humedad disponible en Nicaragua. http://www.ineter.gob.ni/Direcciones/meteorologia/estudios/clasificacion%20de%20humedad.htm
63. INETER (1989). Estudio hidrogeológico e hidroquímico de la región Pacífico de Nicaragua.
64. INIDE (2006). Instituto Nacional de Información de Desarrollo, Compendio estadístico 2003-2004 y Anuario Estadístico 2006.
65. INIDE (2005). Perfil y características de los pobres en Nicaragua 2005, Instituto Nacional de Información de Desarrollo, Encuesta de Hogares sobre Medición de Nivel de Vida.
66. International Water Management Institute (2007). The Comprehensive Assessment of Water Management in Agriculture, System Wide Initiative on Water Management (SWIM). (www.iwmi.cgiar.org/assessment)
67. IPCC (2007). Informe del Grupo Intergubernamental de Expertos del Cambio Climático. Cambio climático 2007, Informe de síntesis. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_sp.pdf
68. Jiménez García, Mario, Montenegro Guillén, Salvador y Yoshiaki Yasuda (2007). Contaminación por mercurio en el lago Xololtán y la salud de poblaciones humanas que habitan en zonas costeras.
69. Jiménez García, Mario, Montenegro Guillén, Salvador y Yoshiaki Yasuda. Contaminación por mercurio en Nicaragua. (2009). El caso de la empresa Pennwalt. Universidad y Ciencia, UNAN-Managua, Año 4, No.7, julio-diciembre de 2009.
70. Kokusai, Kogyo (1993). Resumen del Estudio de Suministro de Agua en Managua.
71. Krásný, J. (1995). Hidrogeología de la zona Pacífica de Nicaragua. Servicio Geológico Checo-INETER. Informe interno.
72. Lacayo Romero, Martha (1995). Pesticidas organoclorados no leite humano de maes Nicaragüenses. Tesis de Maestría, Universidad de Brasilia.
73. Lacerda, L.D. (2003). Updating global Hg emissions from small-scale gold mining and assessing its environmental

impacts. Environmental Geology. 43, 308-314.
74. La Gaceta (2007a). Diario Oficial de la República de Nicaragua, No. 159. Ley No. 626, Ley que Crea la Comisión de Desarrollo Sostenible de la Cuenca del Lago Cocibolca y del Río San Juan. Publicada el 21 de agosto de 2007.
75. La Gaceta (2007b). Diario Oficial de la República de Nicaragua, No. 169. Ley No. 620, Ley General de Aguas Nacionales. Publicada el 4 de septiembre de 2007.
76. La Gaceta (2001). Diario Oficial de la República de Nicaragua, No. 233, Decreto No. 1072001 del Presidente de la República, La Política Nacional de los Recursos Hídricos. Publicado el 7 de diciembre de 2001.
77. La Gaceta (1996). Diario Oficial de la República de Nicaragua, No. 105. Ley 217, Ley General del Medio Ambiente y los Recursos Naturales de Nicaragua. Publicada el 6 de junio de 1996.
78. La Gaceta (1995). Diario Oficial de la República de Nicaragua, No. 118. Decreto No. 33-95, Disposiciones para el Control de la Contaminación Proveniente de las Descargas de Aguas Residuales Domesticas, Industriales y Agropecuarias. Publicado el 26 de junio de 1995.
79. La Gaceta (1958). Diario Oficial de la República de Nicaragua, No. 83, Ley General sobre Explotación de las Riquezas Naturales. Publicado el 17 de abril de 1958.
80. Losilla, M., H. Rodríguez, Schosinsky, G., Stimson, J. y Bethune, D. (2001). Los acuíferos volcánicos y el desarrollo sostenible en América Central, Editorial de la Universidad de Costa Rica, San José.
81. MAGFOR (2008). Ministerio Agropecuario y Forestal de Nicaragua. Subprograma Desarrollo y Reactivación del Riego para Contribuir a la Seguridad Alimentaria en Nicaragua. Octubre de 2008.
82. MAGFOR (2004). Ministerio Agropecuario y Forestal de Nicaragua. Situación actual en el uso de plaguicidas e importaciones autorizadas. Dirección del Registro Nacional y Control de Insumos Agropecuarios. http://www.inta.gob.ni/guias/uso_plaguicidas
83. MAGFOR (2002). Ministerio Agropecuario y Forestal. Dirección General de Estrategias Territoriales, Mapa forestal.
84. MAGFOR (1997). Ministerio Agropecuario y Forestal. Sistema de Información Geográfica, Nicaragua, potencialidades y limitaciones de sus territorios.
85. MARENA (2009). Ministerio de Ambiente y Recursos Naturales. Segunda Comunicación Nacional. Ante la Convención Marco de las Naciones Unidas sobre Cambio Climático, versión prensa, presentación julio de 2009.
86. MARENA (2008a). Ministerio de Ambiente y Recursos Naturales. Informe Técnico Nicaragua Cuenca No. 64. Proyecto "Fomento de las capacidades para la Etapa II de adaptación al cambio climático en Centroamérica, México y Cuba".

PAN10–00014290.
87. MARENA (2008b). Ministerio de Ambiente y Recursos Naturales. Escenarios de cambio climático de Nicaragua a partir de los resultados del modelo PRECIS [Centella, A., Bezanilla, A. (eds.)]. Proyecto Segunda Comunicación Nacional sobre Cambio Climático, NIC10–00036532. Oficina Nacional de Desarrollo Limpio, MARENA.
88. MARENA (2008c). Ministerio de Ambiente y Recursos Naturales. Segundo inventario nacional de gases de efecto invernadero, Nicaragua, Año de referencia 2000.
89. MARENA (2007). Ministerio de Ambiente y Recursos Naturales. Propuesta Plan Ambiental de Nicaragua 2005–2011. Borrador final. Gobierno de Nicaragua. Ministerio del Ambiente y los Recursos Naturales, marzo de 2007.
90. MARENA (2005a). Ministerio de Ambiente y Recursos Naturales. Informe de Evaluación de la vulnerabilidad actual de los sistemas recursos hídricos y agricultura en la Cuenca No. 64. Oficina Nacional de Desarrollo Limpio. Proyecto regional: Fomento de las capacidades para la Etapa II de adaptación al cambio climático en Centroamérica, México y Cuba.
91. MARENA (2005b). Ministerio del Ambiente y Recursos Naturales. Plan Nacional de Erradicación de la Basura, noviembre de 2005.
92. MARENA (2004a). Ministerio de Ambiente y Recursos Naturales. Informe Estado del Ambiente en Nicaragua 2003. Segundo informe GEO.
93. MARENA (2004b). Ministerio de Ambiente y Recursos Naturales. Sistema Nacional de Información Ambiental, SINIA, Imágenes del Satélite Landsat, 2001-2003.
94. MARENA (2004c) Ministerio de Ambiente y Recursos Naturales. Bases de la Política Nacional sobre la Gestión Integral de los Residuos Sólidos, Nicaragua, julio de 2004.
95. MARENA (2004d). Ministerio de Ambiente y Recursos Naturales. Primer inventario nacional de fuentes y emisiones de dioxinas y furanos. Nicaragua.
96. MARENA (2003). Ministerio de Ambiente y Recursos Naturales. Plan de Acción Nacional ante el Cambio Climático. Proyecto Primera Comunicación Nacional ante el Cambio Climático [S. Heumann, G. Wilson V., F. Picado T. (eds.)]. PNUD–NIC/98/G31–MARENA.
97. MARENA (2003). Ministerio de Ambiente y Recursos Naturales. Informe Estado del Ambiente en Nicaragua. Managua, Nicaragua.
98. MARENA (2001). Ministerio de Ambiente y Recursos Naturales. Informe Estado del Ambiente en Nicaragua. Managua, Nicaragua.
99. MARENA–PNUD (2000). Evaluación de la vulnerabilidad y adaptación de los recursos hídricos de Nicaragua ante el cambio climático. Cruz Meléndez, O. et al. Proyecto Primera Comunicación Nacional sobre Cambio Climático,

PNUD–NIC/98/G31–MARENA.
100. Marín Ruiz, J. (2007). Insuficiencia renal crónica en Nicaragua. Presentación en Congreso Multidisciplinario de Investigación Ambiental 2007.
101. MEM (2008). Ministerio de Energía y Minas. Potencial y aprovechamiento de los recursos renovables en Nicaragua.
102. MIFIC (2006). Ministerio de Fomento, Industria y Comercio. Propuesta de la Política Industrial de Nicaragua. Proyecto NI-10-00046784 (versión preliminar).
103. MINSA (2007). Ministerio de Salud. Boletín epidemiológico, semana 51, año 2007. http://www.minsa.gob.ni.
104. MINSA (2003). Ministerio de Salud. Situación epidemiológica de la leptospirosis en Nicaragua, Semana Epidemiológica, No. 40, año 2003.
105. Montenegro, S. (2009). Nicaragua, un país con agua y sed. Conferencia magistral. El Guacal 2, 2009.
106. Montenegro, S. (2009). Nicaragua-Plan de Gestión del Gran Lago Cocibolca, Aplicación de Criterios GIRH en la Organización del Plan de Gestión. http://www.gwpcentroamerica.org/uploaded/content/category/1924515248.pdf y http://www.gwptoolbox.org/index.php?option=com_case&id=216&Itemid=41
107. Montenegro Guillén, S. y Jiménez García, M. (2009). Residuos de plaguicidas en agua de pozos en Chinandega, Nicaragua. Universidad y Ciencia, UNAN-Managua. Año 4, No.7, julio-diciembre de 2009.
108. Montenegro Guillén, S. y Jiménez García, M. (2007). Presencia y concentración de residuos de plaguicidas y contaminantes biológicos en el agua de pozos para consumo humano en localidades de antiguas plantaciones bananeras en el occidente de Nicaragua. Proyecto CNU. Informe final. 1.
109. Montenegro Guillén, S. (2006). Gran Lago Cocibolca, ¿reserva nacional de agua potable para Nicaragua? www.ecoportal.net/content/view/full/59427
110. Montenegro Guillén, S. (2003). Lake Cocibolca/Nicaragua. In Lakenet (ed.) World Lake Basin Management Initiative, Regional Workshop for Europe, Central Asia and the Americas, held at St. Michael's College, Vermont, June 18-21, 2003.
111. Nicaraguan Research Center for Aquatic Resources (CIRA/UNAN) and National Institute for Minamata Disease, Japan (2007). Final Report on Environmental Contamination from Mercury in Lake Xolotlán, Nicaragua: Human Health Risk Assessment to Interamerican Development Bank.
112. OPS (1996). Organización Panamericana de la Salud. Vigilancia Ambiental. Fundación W.K. Kellogg. Serie HSP-UNI/Manuales operativos PALTEX.
113. OPS-OMS (2004). Organización Panamericana de Salud. Estrategia sectorial de Agua Potable y Saneamiento de Nicaragua, noviembre de 2004.
114. OPS/OMS-DANIDA (2002). Diagnóstico sobre la exposición y

efectos del uso de los plaguicidas en la Región Autónoma del Atlántico Norte, RAAN. Serie Diagnósticos 16. Proyecto Plagsalud. Organización Panamericana de la Salud-Organización Mundial de la Salud Nicaragua, febrero de 2002.

115. ONU (1974). Organización de Naciones Unidas. Investigaciones de aguas subterráneas en la región de la costa del Pacifico. Zona de Chinandega. Vol. I y II. New York.
116. PANic (2001). Plan Ambiental de Nicaragua para los años 2001-2005. Gobierno de Nicaragua.
117. Parello, F., Aiuppa, A., Calderon, H., Calvi, F., Cellura, D., Martinez, V., Militello, M., Vammen, K., Vinti, D. (2008). Geochemical characterization of surface waters and groundwater resources in the Managua area (Nicaragua, Central America). Applied Geochemistry, doi: 10.1016/j.apgeochem.2007.08.006
118. PARH (1997). Plan de Acción de los Recursos Hídricos de Nicaragua. Evaluación rápida de los recursos hídricos.
119. PHIPDA (2003). Plan Hidrológico Indicativo Nacional y Plan Anual de Disponibilidad de Agua, 2003. Diagnóstico de los recursos hídricos por cuenca hidrográfica.
120. Picado, F. (2008). Fluvial transport and risk of mercury in a gold mining area. Tesis Doctoral de la Universidad de Lund, Suecia, Departamento de Ecología, Ecología Química y Ecotoxicología.
121. PROCUENCA SAN JUAN (2004a). Informe técnico final sobre agua y clima, Enfrentando la variabilidad del clima en una cuenca transfronteriza de América Central: la Cuenca del Río San Juan, Proyecto PROCUENCA. http://www.oas.org/sanjuan/spanish/documentos/dialogo/dialogo/04-tecnical_report/03-BasinDescription.html
122. PROCUENCA-SAN JUAN (2004b). Integración de los estudios básicos del Proyecto “Formulación de un Programa de Acciones Estratégicas para la Gestión Integrada de los Recursos Hídricos y el Desarrollo Sostenible de la Cuenca del Río San Juan y su Zona Costera”.
123. Programa Conjunto del Milenio (OMS/UNICEF) de Seguimiento del Abastecimiento de Agua y del Saneamiento (PCM) (2010). Progresos en materia de saneamiento y agua. Informe de actualización.
124. PNUD (2007-2008). Programa de las Naciones Unidas para el Desarrollo. Informe sobre Desarrollo Humano, 2007-2008.
125. PNUD (2006). Programa de las Naciones Unidas para el Desarrollo. Informe sobre Desarrollo Humano. Más allá de la escasez: poder, pobreza y la crisis mundial del agua.
126. PNUMA-MARENA (2000). Reducción del escurrimiento de plaguicidas al mar Caribe. Informe Nacional de Nicaragua. Proyecto GEF (Global Environment Facility). Dirección General de Control Ambiental. Dirección de Vigilancia y Control Ambiental.

127. Proyecto RepCar (2009). Proyecto "Colombia, Costa Rica y Nicaragua: Reduciendo el Escurrimiento de Plaguicidas al Mar Caribe" (GEF-REPCar), "Monitoreo del Escurrimiento de Plaguicidas al Caribe Nicaragüense". http://cep.unep.org/repcar/coastal-monitoring
128. Proyecto RepCar (2010). Proyecto Reduciendo el Escurrimiento de Plaguicidas al Mar Caribe. Informe de país sobre importaciones de plaguicidas correspondiente al periodo 2004-2009, Nicaragua.
129. SINIA (2008). Sistema Nacional de Información Ambiental. Medio ambiente en cifras: Nicaragua 2004-2007. Managua. http://www.sinia.net.ni
130. SINIA-MARENA (2009). Borrador del Informe Estado del Ambiente, GEO, 2007-2008.
131. http://www.sinia.net.ni
132. Telmer, K., Costa, M., Angélica, R. S., Araujo, E. S., Marice, Y. (2006). The source and fate of sediment and mercury in the Tapajós River, Pará, Brazilian Amazon: Ground- and space-based evidence. Journal of Environmental Management, 81, 101-113.
133. UNICEF-ASDI (2004). Contribución al estudio de cinco zonas contaminadas naturalmente por arsénico en Nicaragua, octubre de 2004.
134. UNICEF, ENACAL, MINSA (2005). Evaluación rápida de la calidad del agua de bebida. Informe final.
135. Vammen, K., Pitty, J., Montenegro Guillén, S. (2006). Evaluación del proceso de eutrofización del lago Cocibolca, Nicaragua y sus causas en la cuenca. Eutrofización en América del Sur, consecuencias y tecnologías de gerencia y control, Instituto Internacional de Ecología, Interacademic Panel on International Issues, 35-58.
136. Vargas, O. R. (2007). Centroamérica: Las Metas del Milenio, Centro de Estudios de la Realidad Nacional (CEREN).
137. Velásquez, G. (1994). Diagnóstico da contaminacão ambiental gerada pela atividade mineraria sobre os Rios Súcio, Mico e Sinecapa, Nicaragua. MSc Dissertation, Centro de Geociencias, Univesidade Federal do Para, Belém.
138. WWAP (2006). UN-Water/World Water Assessment Programme. Water, a shared responsibility. The United Nations World Water Development Report 2.
139. Weyl, R. (1980). Geology of Central America. Beiträge zur Regionalen Geologie der Erde, Gebrüder Borntraeger Verlagsbuchhandlung, Science Publishers, Stuttgart.
140. World Bank: Agricultural Land Use; Selected Countries (2001).
141. Yale Center for Environmental Law & Policy (2010), Environmental Performance Index 2010. http://epi.yale.edu/

Peru, Cordillera Blanca

Water Resources in Peru
A Strategic View

Julio M. Kuroiwa

Laboratorio Nacional de Hidráulica.
Universidad Nacional de Ingeniería, Lima, Perú.

Key words: Peru, water resources, water availability, environment, water issues, water management, research and development.

1. Introduction

This paper summarizes the current situation of water resources availability in Peru. A brief description of Peru's spatial water resources distribution and population has been included. Water uses and future trends are quantitatively explained. Water related disasters are briefly described in this document. Recent government efforts to strengthen national, regional and local water authorities and users have also been commented. The implications of new water related laws are summarized. Finally, research efforts made by a few universities are presented as examples of works conducted in the water resources area.

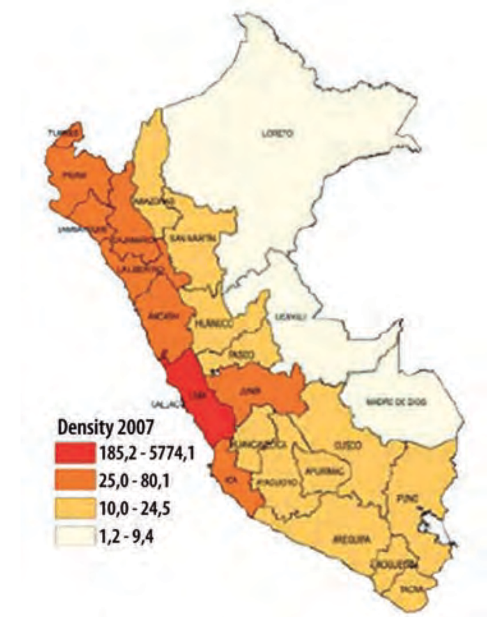
2. Hydric Resources

Peru, with an area of 1,285,216 km^2 and a current population of 28,220,764 million inhabitants as of October 2007, is located on the center of the West Coast of South America. The presence of the Peruvian Current (locally known as Humboldt Current), the Andes range and the Amazon Jungle have created large climate diversity within the same country and a very uneven distribution of the water resources. One hundred and six basins have been identified by the National Resources Institute of Peru (INRENA). Three macro drainage basins contain these major basins: the Pacific Basin, the Atlantic Basin and the Lake Titicaca Basin, which are shown in FIG. 1. The Pacific Basin is composed by hydrographic systems that are located on the Western Slope of the Andes. Most of the Rivers are short and very steep. Most of the rivers´ divides are located at over 5,000 m above the sea level and watercourses are less than 150 km long. The Atlantic Basin (or Amazon Basin) is composed by river systems that are located on the Eastern Slope of the Andes and convey water from the highlands to the Amazon River or a major tributary. The Lake Titicaca Basin is a closed system that includes other sub basins in Bolivia and ends in two lakes: Lake Poopó and Coipasa Salt Lake.

Although one may think of Peru as a country with abundant water resources, with an average 77,534 m^3/inhabitant/year, water resources are very unevenly distributed. The majority of the Peruvian population lives along the basins that convey water into the Pacific Ocean. FIG. 2 shows the population density distribution. Darker shades show greater population density per region. The Peruvian Coast is a very arid area, ranging from hyper arid environments in the South and Central areas and semi arid areas in the North. The precipitation is virtually zero at sea level and near the divides the precipitation is less than 900 mm/year. Precipitation mostly occurs between mid November and mid April. FIG. 3 shows a typical view of the Coast.

SOURCE: ATLAS GEOGRÁFICO DEL PERÚ, 2007

FIG. 1. Drainage Basins in Peru.



SOURCE: INSTITUTO NACIONAL DE ESTADÍSTICA E INFORMÁTICA (2007) DENSIDAD 2007 DENSITY 2007

FIG. 2. Population Density by Region. Population Density Decreases Towards the East.

FIG. 3. Typical View of the Central Coast

Table 1 shows that although annual water availability is only 37,363 millions of cubic meters which represents 1,8% of the country's total availability for the Pacific Basin, 65% of the Peruvian population, 18,315,276 people, live in this area, which results in an availability of 2,040 m^3/person/year on the average. However, some populated centers have an average availability of less than 1,000 m^3/person/year. For instance, the Rimac River Basin, where Lima is located, has a water availability of 148,6 m^3/person/year which is way below the water scarcity treshold. Lima is the second largest city in the world, following Cairo, located in a desert area. However, Cairo is very close to the Nile River, which provides much greater water availability than the Rimac River provides to Lima.

The Amazon Basin, which also includes the highlands, has an annual water availability of 1,998,752 millions of cubic meters, which is 97,7% of the water resources of the nation. With a population of only 8,579,112, the water index is 232,979 m^3/person/day. This is approximately 114 times the water availability of the Pacific Basin.

Table 1. Area, Water and Population Distribution in Peru. Source: ANA (2009) based on INRENA (1995).

Basin	Area (1000 km²)	Water Availability (Mm³/year)	% Water Availability	Population	% Population	Water Availability (m³/inh/yr)
Pacific	279,7	37,363	1,8	18,315,276	65	2,040
Amazon	958,5	1,998,752	97,7	8,579,112	30	232,979
Titicaca	47,2	10,172	0,5	1,326,376	5	7,669
Total	1 285,2	2,046,268	100,0	28,220,764	100	72,510

The Lake Titicaca Basin is part of a closed system formed by four major basins: Lake Titicaca (T), Desaguadero River (D), Lake Poopó (P), and Coipasa Salt Lake (S). These four basins form the TDPS system of which the main element, Lake Titicaca (8,400 km^3), is the largest in South America. (www.unesco.org/water/, 2009). The area of the Lake Titicaca basin within Peruvian borders is 47,200 km^2. The population in this area is 1,326,376, which is 5% of the total. The annual volume of surface water is 10,172,000 m^3, 0,5% of the total resources of Peru. Annual water availability is 7,669 m^3/person/year in the Lake Titicaca Basin.

FIG. 5. View of the Central Peruvian Sierra. Altitude is Above 4,200 MSL.

FIG. 6. View of the Peru´s low Jungle, a Very Wet Area.

3. Water Uses in Peru

The national water consumptive use is approximately 20,072 Millions of Cubic Meters per year (Mm^3/year), of which 80% is exploited in agricultural activities, 18% is used in municipal and industrial activities and 2% is used by the mining industry. However, water consumption is increasing in the latter economic activity. Non consumptive use (including power generation) is estimated at 11,139 Mm^3/year.

FIG. 4. View of the Peruvian Sierra. Medium Altitudes

Agricultural Activities

The potential area for reclamation is 6,411,000 Ha. However, only 1,729,000 Ha are being irrigated. In the Coastal region 1,080,000 Ha are irrigated, but only 836,000 Ha are actually being farmed for commercial purposes. The Peruvian Sierra (highlands) has 18% of the area and the Jungle (Selva) has 5% of the farmland.

The main difficulties of developing agricultural activities in the highlands are the mountainous relief, water scarcity and the weather, particularly when the areas are over the 3,500 meters above sea level. The thin topsoil, which is easily eroded away when the soil has been altered by tilling, and the hot weather, are the main difficulties for the development of agricultural activities, particularly in the lowlands. Average irrigation efficiencies range between 35 to 40%.

Municipal Water and Industrial Activities

Municipal water and sewage service is provided by 45 service provider companies (SPC) that are licensed by SUNASS (National Superintendent of Sanitary Services, acronym in Spanish). They provide water in 114 of the 194 provinces Peru has. Provinces are sub divisions of the Regions. In Metropolitan Lima, 86.9% has access to water services and 69.5% has sewage connected to the wastewater system. The Peruvian Government is building a new water treatment plant in Lima upstream of the existing one and is also expanding the service to a number of communities. The goal is to provide full coverage by the year 2011, to partially comply with the Millennium Challenges. In towns where population is less than 2000, administrative boards partially cover the costs of water supply with a monthly contribution.

Industrial Use

Most of the industrial activities are conducted in Lima and some major cities along the coastline of Peru. Water consumption in industrial activities is 1103 Mm^3/year in the Pacific Drainage Basin, 92% of the total industrial use. Industrial use is 49 Mm^3/year in the Atlantic Drainage Basin, which represents 7% of the total.

The Lake Titicaca basin uses 3 Mm^3/Year, which is 1% of the total. The main industrial activities that consume water are: the leather industry, textiles industry, production of beverages, food production, paper manufacturing and oil refineries.

Mining Use

Peru is the top producer of silver in the world with 111,6 million ounces of mineral in 2006. It is also the third producer of zinc, contributing with 12% of the total production worldwide and the fifth producer of gold, with 203,268 kg in year 2006. It is also among the top ten producers of plumb, tungsten, cadmium, bismuth, tellurium, molybdenum, and other metals. Currently, mining exports represent 45,9% of the total sales overseas.

The use of water in the mining industry has been growing as the production worldwide increased and the demand for metals rose to unprecedented levels. The order of magnitude is 206,7 Mm^3/year of which 73% are used in the Pacific Drainage Basin, 26% are used in the Atlantic Drainage Basin and 1% in the Lake Titicaca Drainage Basin.

Hydropower Generation

Potential of hydropower generation is directly related to water resources availability and the topography of the area being considered for power development. In a particular project, persistence of discharge and difference of elevation between the forebay and the tailwater are components which allow one to calculate the gross power available. A study for evaluation of the potential for power generation in Peru was conducted in 1969 by the Association Lahmeyer – Salzgitter. It was sponsored by the former Federal Republic of Germany through the German Society of Technical Cooperation (GTZ, acronym in German), International Bank for Reconstruction and Development (IBRD) and the Peruvian Government.

The evaluation considered potential power plants that could produce 20 MW or more. Sites in the lower Amazon Jungle were not considered, because of the lack of data, mainly topographic surveys and hydrological information, unfavorable geologic conditions and potential deleterious effects in the environment caused by the flooding of large areas. The theoretical power potential was estimated in 200,000 MW. This study was updated in 1979 by the Ministry of Energy and Mines (MEM, acronym in Spanish). In both cases, the reports mentioned that one of the main problems for the studies was the lack of data. Table 2 summarizes the number of power plants and their potential of power generation. It is worth mentioning that ELECTROPERU (the Government Owned Power Company) developed preliminary studies for hydropower generation of electricity, particularly in those sites in which the population heavily depended on thermal power. Sites in the Peru's Lower Jungle mostly use thermal power plants due to the lack of hydrologic information on suitable locations and the absence of adequate connectivity in the area. For instance, the Napo – Mazán project consists of using water taken from the Mazán River, a tributary of the Amazon River, and diverting it to a power plant. Power is generated taking advantage of the difference of elevation between the Mazán River and the Amazon River, which is approximately 6 m (19,7 ft). This project could provide electric power to Iquitos, the capital of the Loreto Region, and other cities in the Amazon area. Currently, there are a number of power generation projects being developed. A number of companies have already applied for permits and it is expected that new power plants will be built in the short and medium term.

Table 2. Number of Power Plants and Range of Power Generated in MW.

Power generate	Number of power plants
More than 500 MW	1
Between 100 y 500 MW	9
Between 50 y 100 MW	4
Between 10 y 50 MW	10
Less than 10 MW	9

Harald Federicksen (1996) pointed out that it is important not to waste time in coming up with real solutions for problems generated by the scarcity of water resources. There are four points that are key to understand the problems:

a) Scarce time to take preventive measures.
b) Limited measures which are currently available to mitigate the effects of water scarcity.
c) Competition for funds and resources allocations.
d) The minimum ability to handle droughts when they occur.

The last point is precisely the main problem related to power generation. Most of the hydropower plants in Peru are run-of-river. This means that water is taken directly from the river, with no significant storage capabilities, and is diverted to the power plant. This means that energy production in Peru is very vulnerable to droughts, although new thermal plants have been built in the last years due to the high demand for energy. Therefore, there is an immediate need to increase power generation.

4. Environmental Issues and Water Pollution

Human activities have an impact on the surface and underground water resources. Agricultural activities, construction of infrastructure, industrial uses, mining, municipal water use and ranching have an impact on the environment.

Agricultural activities contribute to the pollution of watercourses. Use of pesticides and fertilizers on crops causes contamination of surface water and groundwater. During the rainy season, fertilizer and pesticide residues are washed away and mixed with runoff and diminish the water quality of streams they enter. For instance, contamination by agrochemicals has been reported in Lake Chinchaycocha, located in the Central Andes of Peru. Extraction of cattails also occurs because they are used as forage for livestock. Livestock contributes to the compaction of the wetlands surrounding the lake, destroying the habitat for native species. Mining activities also play a major role in the decrease of native fauna in this lake.

Aquifers are also vulnerable to excessive exploitation. They are depleted when the rate of demand is larger than the recharge rate. In coastal areas, depletion of the aquifer may also cause intrusion of salt, as it happens in La Yarada, in Tacna, near the Peru-Chile border.

Mining activities in Peru precede the times of the Spanish Conquest. Gold, silver and copper jewelry and other metal artifacts have been found in cultures that are even 3,000 years old. Mining activities become increasingly intense during colonial and republican times. During the 19th and 20th centuries large investment were made in the exploitation of mine sites. At the beginning of the 20th century the investment was mainly private and foreign companies invested in Peru. CENTROMIN PERU was created when several mining sites were expropriated by the Peruvian Government during the 60´s.

Although the mining industry is heavily regulated nowadays, being the most important investors those who exploit mines in first world countries and follow their standards, passives from the past remain throughout the Peruvian territory and mitigation measures are needed to diminish pollution of watercourses. Unregulated mining activities have left untreated mine sites. Some tailings are exposed to the environment and are eroded away during the rainy season, rapidly diminishing the quality of water. FIG. 7 shows an abandoned mine tailings on the right bank of Colorado River in the Northern Andes of Peru. Abandoned quarries, acid drainage are also issues which are gradually being solved in locations where investment is made by new investors which are obligated to assume the passives left by previous concessionaires.

FIG. 7. Mine tailings on the Left Bank of Colorado River in Cajamarca, Northern Peruvian Andes

Large scale municipal water treatment plants are practically non-existent in Peru. For instance, several collector sewages convey wastewater from Lima, the capital city, to the Pacific Ocean. Wastewater is mainly domestic and industrial. Total annual volumes and percentages of wastewater treated and untreated are shown in Table 3.

A large amount of water is left untreated. In most cases, wastewater is discharged in watercourses or water bodies, thus polluting the environment.

One of the first major treatment plants wastewater, PTAR Taboada, shall be built in Callao, the coastal city adjacent to Lima, and will process part of the effluents from the capital city. A Spanish company won the bid to perform the work in 2009. A financial agreement was reached and preliminary works started on July 20, 2010. SEDAPAL, the water utility and wastewater in Lima will build other plants in the following years, according to information available on its website (www.sedapal.com.pe, 2011).

According to the Pan-American Health Organization (PAHO), 80% of the hospital bed occupation is caused by drinking contaminated water. Because of lack of culture of water, most cities and towns municipal services pour their sewage and solid wastes in water bodies and rivers.
This problem is especially critical in large cities like Lima with some 8 million inhabitants and Arequipa with about 1 million people which pollute the Rimac and Chili rivers respectively beyond permissible limits.

Contamination reduces the volume of water of good quality and also substantially increases the cost of drinking water treatment. In medium sized cities and towns this problems is even more critical. To fulfill one of the 8 Objectives of the UN Millennium Declaration to reduce the infant mortality, it is necessary to lower the water contamination caused by the population, and agricultural and mining activities. It is a key issue to contribute to reduce poverty in the country.

Table 3. Total Annual Volume and Percentages of Wastewater with and Without Treatment.

Wastewater produced by sanitation services	Volume per year (m^3/year)	Discharge (m^3/s)	% Treatment
With treatment	217,253,807	6,89	29,10
Without treatment	530,027,896	16,81	70,90
Total	747,281,703	23,70	100,00

5. Water and Society

Peru´s population is as diverse as its geography. There are three official languages in Peru. Spanish is Peru's official language, but also are Quechua and Aymara where they prevail. Thirty three indigenous languages (spoken mainly in the Amazon jungle) are also recognized as part of Peru's cultural heritage. Views on the use of water are as diverse as the Peruvian population. Scarcity of fresh water in the Coast and the Mountains and the increasing use of this resource have led to conflicts among users. Peru has created a system for defending its citizens´ rights against the abuse of the Government or large companies or institutions called People's Defensorship (Defensoría del Pueblo). (www.defensoria.gob.pe). This institution constantly reports conflicts that occur in Peru every month.

Environmental issues are usually the main cause of conflicts (51 % as of May 2009). The majority of these conflicts are mostly related to water use. In the jungle and lower jungle conflicts arise from the opposition of various native ethnic groups who have witnessed the imbalances caused by intense uncontrolled human activities. However, there are places that have been taken by informal miners whose activities are not controlled by the Government. The invaders face no opposition from the natives who accept the monetary benefits of gold exploitation.

Damages to the environment are very severe because miners use mercury during the extraction process (El Comercio, April 24, 2009). In Madre de Dios region, gold miners have already deforested 150 000 Ha of primary forests and surrounding wetlands have also been affected. Minister of the Environment Antonio Brack called damages caused by informal gold miners in SE Peru as "monstrous". Seven ministries evaluated damage caused by the miners in 2009. On February 19th and 20th, 2011, in a joint operation by the Army and the Peruvian Police, 12 dredge barges were destroyed. They were used to extract gold from the river beds. A few NGO and regional organizations have protested this measure although the news was well received by the general population.

There are places in Peru where underground and surface waters naturally carry heavy metals. One of these locations is located in the Peru–Chile border highlands. The population, which lives in small rural communities, used to be exposed to water with high Arsenics content. Technological solutions have been proposed by Rodriguez (2007), using technology that can be easily applied by the inhabitants of this area.

6. Extreme Events: Floods and Droughts in Peru - Reducing the Risk of Disaster of Climatic Origin

The Intergovernmental Panel on Climate Change (IPCC) working groups I to III have predicted in their reports of 2007 that the average world temperature will have an increment from 1.5 to 4° C during the 21st century (IPCC, 2007). Therefore, it is expected that climatic disaster as El Niño will be more severe and frequent in the next decades. El Niño 1982-83 caused severe flooding in the country northwestern coast and drought in the high plateau of the Titicaca Lake basin which is located, over 12 000 feet high. These two negative effects caused material loses of 6,2% of the country GNP. To reduce the losses in urban areas in Peru was initiated the Sustainable Cities Program in 1998 focused on its first attribute: the cities safety. The best argument to convince the chief of the El Niño Reconstruction Committee (CEREN) at the same time, Peru prime minister was that the flooding maps.

El Niño 1997-98 were practically carbon copy of those of El Niño 1982-83 of main cities affected by both El Niño as Tumbes, Piura Talara, Paita, etc. In addition to the functions of the National Water Authority of Peru (ANA) that is to have an efficient water use in the country, including disaster reduction, Peru's National Center for Strategic Planning (CEPLAN) has nominated a specialist on El Niño Southern Oscillation (ENSO) to reduce its future negative impact.

Negative trends in precipitation patterns have been observed in Chile and part of the Western Coast of South America. Southern Peru may be affected by diminished water availability. Positive trends in precipitation have been observed in the Amazonian region, which may lead to more frequent flooding in riverside areas.

The Andean glaciers are disappearing due to an increase in air temperature at high altitudes and diminishing trend in precipitations. Figure 8 (Morales-Arnao, 1982 – 1997 – 2005) shows glacier Yanamarey evolution in the course of 23 years. The same phenomenon has been observed in all Peruvian glaciers. Therefore, water reserves in form of ice and snow are diminishing at a fast rate and may adversely affect water availability in the near future.

FIG. 8. Yanamarey Glacier Between 1982 and 2005. (Morales Arnao, 1982, 1997 and 2005).

7. Institutional Framework

The importance politicians, entrepreneurs and the society at large gave to Peru's natural resources is reflected in Peru's national coat of arms (or Great Shield) which shows a Vicuña, a Quinoa tree and a cornucopia, which represent the Animal, Vegetal and Mineral Kingdom, respectively. This reflects the importance natural resources have in Peru's economic life. In fact, Peru has been a supplier of raw materials to industrialized countries for about 200 years.

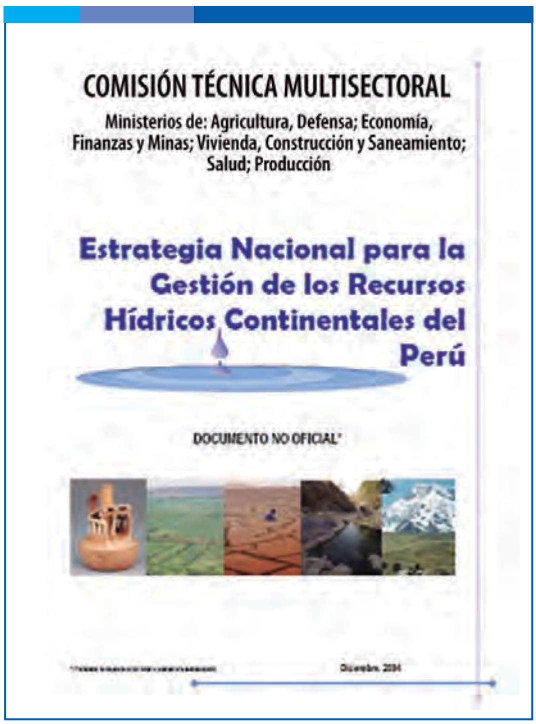
Peru is a Unitarian country. Its constitution establishes that natural resources, renewable or not, are property of the State and its exploitation is given in concession to the private sector, provided that previously established conditions are fulfilled (Peru's Constitution, 1993). A large portion of Peru's income is based on the exploitation of its natural resources, particularly mining activities, large scale fishing, and others. Agricultural and food industry is becoming increasingly important as well. The lack of planning and control of economic activities has led to environmental disasters that have caused the contamination of soil and water of a number of basins. Air pollution also occurs as a consequence of transportation of contaminants. Damages caused by the environment led to the creation of the Ministry of the Environment in 2008.

The institutions in recent years were responsible care of water resources in Peru were:

National Institute of Natural Resources (Instituto Nacional de Recursos Naturales, INRENA)

Before to the creation of the National Water Authority (Autoridad Nacional del Agua, ANA), INRENA, the National Institute of Natural Resources in Peru, was in charge of conducting the necessary actions to make use of the renewable natural resources in a sustainable way, preserve the wild biologic diversity and protect the rural environment.
This institute was part of the Ministry of Agriculture and had a Superintendent of Water Resources who used to be in charge of planning water allocations and coordinate with users along with the ministry of Agriculture. Hydrologic research was also conducted by INRENA to estimate the availability of water resources on a per basin basis. Several INRENA officers championed the publication of a non-official document called "National Strategy for Peru´s Continental Water Resources Management" in which they included views from 7 ministries which are: a) Agriculture; b) Defense; c) Economy and Finance; d) Mines and Energy; e) Housing, Construction, Water Supply and Sewerage; f) Health and g) Production (FIG. 9).

In recent years, the growth of water use because of population growth, new economic activities that require water, increase of polluted waters, and increase of conflicts among users has led to the Government and the society and large to demand the creation of a National Water Authority that dealt with water issues from a comprehensive point of


COMISIÓN TÉCNICA MULTISECTORAL
Ministerios de: Agricultura, Defensa; Economía, Finanzas y Minas; Vivienda, Construcción y Saneamiento; Salud; Producción

Estrategia Nacional para la Gestión de los Recursos Hídricos Continentales del Perú

DOCUMENTO NO OFICIAL*

FIG. 9. Unofficial Document (Anonymous, 2004). National Strategy for Peru´s Continental Water Resources Management.

view. This new institution was created in March 2008 by Legislative Decree 997. The National Water Resources System was created shortly thereafter.

National Water Authority (Autoridad Nacional del Agua, ANA)

The recently created National Water Authority (ANA, acronym in Spanish) is the government institution in charge of conducting the necessary actions to secure the sustainable use of water by all sectors on a per basin basis within the integrated natural resources management framework. Strategic alliances are established with regional and local authorities, and the social and economic actors involved in water issues. Its main functions are to produce the policies and the national water resources strategy, manage and formalize water rights, promote the fair distribution of water, and to facilitate the solutions of conflicts among users. ANA (2009) recently published the book "Política y Estrategia Nacional de Recursos Hídricos del Perú" which provides insight in a general analysis of the current situation and proposes courses of action to solve the problems generated from the uneven distribution of water resources, its scarcity and multiple uses. This document was largely based on Anonymous (2004) which was promoted by INRENA officers (FIG. 10).

FIG. 10. Document Published Recently by ANA (2009).

National Water Resources System (Sistema Nacional de Recursos Hídricos, SNRH)

The National Water Resources System (NWRS) was created by Legislative Decree 1081 in September 2008. Its main goal is ensure that all sectors of the government: national, regional and local, who have any kind of authority on water issues and users who can be individuals, associations or companies work in a coordinated manner to make sure water resources are used in a sustainable and effective way considering the criteria of quantity and quality of water and opportunity of the interventions. The following institutions, agencies and private participants are part of the NWRS:

1) National Water Authority
2) Ministry of the Environment
3) Ministry of Agriculture
4) Ministry of Housing, Construction and Sanitation.
5) Ministry of Health
6) Ministry of Production
7) Ministry of Energy and Mines
8) Public Agencies that are related to water management at regional and local levels.
9) Basins´ Councils
10) Public and private water operators
11) Water users´ boards

Peru's Water Resources Law (Law 29338 – March 2009)

Peru's new water resources law has been published in March 2009. This new law establishes that ANA is the top technical and normative authority to deal with water issues in Peru. The National Court of Resolution of Water Controversies is part of ANA and its mandates are final and can only be appealed by judicial means. Basin Councils are also established. They participate in the planning and coordination of water uses. They may cover one or two regions, in which case each region will provide the necessary members to insure that all sectors of society are fairly represented by this authority.

Users´ boards are also regulated. They operate, manage and maintain water distribution infrastructure, decide on water distribution amongst its members and also charge for the use of water.

Farmers´communities and Tribal Communities rights are also recognized in this law. Water may be used according to their traditions. These organizations have the same rights and obligations than the users´boards. Priorities in water use are clearly defined. The top priority is primary use, which is direct consumption by human beings. Population use is the second priority. This is consumption in a network of domestic users. Productive use comes third. This use is linked to economic activities.

8. Recent Efforts in Water Resources Research in Peru

The Hydraulic Resources - University Research Consortium (HR-URC) of Peru is composed by eight universities qualified by CONCYTEC, the National Council of Science, Technology and Innovation of Peru, a government agency that promotes scientific and technological research in Peru. These universities are: Universidad Nacional de Ingeniería (UNI), Universidad Nacional Agraria – La Molina (UNALM), Universidad Peruana Cayetano Heredia (UPCH), Pontificia Universidad Católica del Perú (PUCP), Universidad Nacional Mayor de San Marcos (UNMSM), Universidad Nacional de Trujillo (UNT), Universidad Nacional San Agustín de Arequipa (UNSAA) and Universidad Nacional San Antonio Abad del Cuzco (UNSAAC). They were ranked and qualified mainly based on research production. HR-URC has organized three meetings so that the universities that are members of HR-URC could present their present and future research projects. In addition, other organizations such as regional (state) and national agencies participated and presented their expertise as well as the issues they deal with on a daily basis.

CONCYTEC has acted as a facilitator to produce ProHidro, the National Plan for Research on Science, Technology, and Innovation in Water Resources. Members of ProHidro are university instructors and researchers, public and private water resources managers, regional (state), local and national government officers.

Five main research areas have been identified by members of ProHidro as follows:

a) Water availability.
b) Water resources integrated management.
c) Water supply and wastewater.
d) Water quality.
e) Risk management.

Research areas have also been divided in lines of research and finally, research projects were proposed. One of the main difficulties consists of the lack of reliable hydrologic and meteorological data. Some examples of research produced by Peruvian scholars are presented in the next section. Since 2009, three universities that form the Strategic Alliance: UNALM, UNI and UNMSM have organized three National Water Congresses in which water issues have been presented in a multidisciplinary way.

The congress was developed and chaired by the three institutions in the order mentioned before. Research on subjects such as hydrology, hydraulics, water resources management, social and environmental issues, etc. have been covered. Institutional framework has also been an important subject, due to the recent creation of ANA. Participants included researchers from national and foreign universities, public officers, NGOs, private consultants, Utility Companies, Water Boards, and the private sector in general.

Research on Water Availability

The main objective of this are is to evaluate present and future water resources availability on a basin by basin basis. Several research projects are being conducted in this area. The National Agrarian University at La Molina (UNALM) is currently studying water resources availability in the Peruvian Andes, particularly in the White Range where global warming has caused retreat of the snow covered areas. They are also studying rainfall-runoff relations in the Amazon Jungle of Peru. Both projects are supported by French universities.

The National University of Engineering (UNI) is studying rainfall-runoff relations in several natural settings in Peru. Peru's area and weather diversity makes it necessary to study water resources in different geographical conditions. There is a lack of real time records of precipitation and discharge in Peru. Therefore, techniques have to be developed from basins that have better information than others. Two research projects have been recently concluded by UNI graduate students. In the first one, a Master's thesis has shown that it is possible to predict mean daily discharges based on daily precipitations in a basin with very limited data by using conceptual models such as the Tank and NAM models. The Major National University San Marcos (UNMSM) is conducting research on groundwater resources near marine areas. The objective is to study potential solutions for avoiding intrusion of saline water in coastal wells.

Research on Water Quality

The purpose of this research area is to improve the capacity of monitoring, contamination reduction and preservation of water quality.

A team led by Dr. Guy Carvajal has been working on the reduction of contamination levels of Arsenic, Cadmium and Lead from polluted water by filtering water through sand. The method consists of using a mix of magnesium, sand and marine spores. Marine spores are used to oxidize magnesium, which creates a barrier that traps heavy metals. Results clearly show that after two hours of filtering, concentration of heavy metals decreases below OMS permissible limits. Dr. Guy Carvajal is a micro biologist specialized in Genetics who works as a professor at the school of Environmental Engineering of the National University of Engineering. Dr. Juan Rodriguez, from the school of Science of UNI, has developed a method to remove arsenic from water. Surface and subsurface water is prone to contamination from the soil whose arsenic content is high in rural areas in Southern Peru (near the Peru – Chile border). Water is poured into a plastic bottle containing water and an iron wire. This is exposed to sunlight after lime drops were added to water. This induces settling of arsenic. Arsenic is removed from the bottom of the container afterwards and disposed of properly.

Research on Water Social Aspects

PUCP has developed numerous research projects dealing with water management on a local and regional scale. Case studies about contamination in the Huatanay River Basin and users´ conflicts in micro basins have been documented and published.

9. Conclusions and Recommendations

1) Peru has a very uneven distribution of water resources and population. People had a strong tendency to populate the coast, which is a very dry area. Water availability per capita is one of the lowest in the world.
2) Most of consumptive water use is agricultural, followed by municipal and industrial activities, and mining. This latter activity is gradually increasing its water consumption.
3) Contamination of water bodies and streams is an issue that needs to be solved. Passives left from past human activities, untreated municipal effluents, and current unregulated economic activities are harming water resources in Peru.
4) Water related extreme events affect the life and economy of Peru. On one hand El Niño Southern Oscillation causes flooding in the Northern Coast of Peru and on the other hand, may cause severe droughts in other regions.
5) Glaciers are rapidly disappearing from the Peruvian Andes. This may significantly affect water resources availability in the near future.
6) Water related laws and regulations have been rapidly changing during the last years to deal with water related problems in a comprehensive way. The Ministry of Environment and the National Water Authority were created in 2008. The Water Resources Law and the National Water Resources System were created this year.
7) The new water resources law confers full power to ANA to deal with water issues on a national scale. It also provides a framework in which national, regional and local authorities and users can use water in a sustainable, effective and efficient way. Functions and limitations of users´ boards are established. Traditional and ancestral uses by farmers´ communities and minority ethnic groups are recognized as well.
8) Research efforts are made in Peru in the water resources area. Most of the work is concentrated in a few large universities. Main research areas are water availability and water quality. The main difficulty for conducting research on water availability is the lack of reliable data. Government officers and the private sector have also developed some work that has been presented in the National Water Congresses.

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11. References

1. ANA 2009. Autoridad Nacional del Agua. Política y Estrategia Nacional de Recursos Hídricos del Perú. Lima, Perú.
2. ANA Autoridad Nacional del AGUA: http://www.ana.gob.pe/
3. Anonymous (2004). Estrategia Nacional para la Gestión de los Recursos Hídricos Continentales del Perú. Documento no Oficial. Ministerios de: Agricultura; Defensa; Economía y Finanzas; Energía y Minas; Vivienda, Construcción y Saneamiento; Salud; Producción.
4. Frederiksen, Harald (1996). Water Crisis in Developing World: Misconceptions about Solutions. Journal of Water Resources Planning and Management. Vol 122. N° 2. American Society of Civil Engineers.
5. Instituto Nacional de Recursos Naturales: http://www.inrena.gob.pe/
6. Intergovernmental Panel on Climate Change (2008). Climate Change and Water. IPCC Technical Paper VI.
7. Kuroiwa, Julio and Romero, Fernando (2008) Potencial Hidroeléctrico y Energías Renovables en el Perú. Capítulo del Libro: Seguridad Energética en el Perú. Consejo Departamental de Lima. Colegio de Ingenieros del Perú.
8. Ministerio de Energía y Minas. (1968, 1979) Evaluación del Potencial Hidroeléctrico Nacional. Ministerio de Energía y Minas. Lima, Perú.
9. Ministerio de Energía y Minas. Revista En Cifras. Agosto 2008. Ministerio de Energía y Minas. Lima, Perú.
10. Ministerio de Energía y Minas. Revista En Cifras. Diciembre 2007. Ministerio de Energía y Minas. Lima, Perú.
11. Ministerio de Energía y Minas. Revista En Cifras. Diciembre 2006. Ministerio de Energía y Minas. Lima, Perú.
12. Rodriguez, Juan (2007). Talk on Reduction of Arsenic in Southern Peru. University Consortium – Water Resources Research. National Hydraulics Laboratory.
13. Servicio de Agua Potable y Alcantarillado de Lima (SEDAPAL): http://www.sedapal.com.pe/obras/proyobras.php

American Falls

The Water Resources of the United States and their Management

Henry Vaux, Jr.

University of California

1. Introduction

In the United States, the availability of water, the patterns of use and the problems of water management are highly variable both in terms of time and location. This variability means that it is frequently difficult to generalize about the features of the waterscape. Nevertheless, the most prominent and consistent descriptor of the water situation in the United States is that water is scarce.

With the possible exception of times of flood there is generally not enough water to meet all of the wants for it, given its availability, levels of use and the circumstances under which it is managed. The pervasive existence of water scarcity and the fact that it is continuing to intensify, results from the fact that demands for water continue to grow as its population and economy grow while supplies remain either static or in decline. Declines can be caused by deteriorating water quality, ground water overdraft, and shifting trends in the quantities, timing and form of precipitation. The impact of these factors differs from region to region and this means that scarcity itself, while pervasive, exists in differing degrees across the face of the country.

Despite its position as the most economically developed and wealthiest nation of the Americas, the United States faces most of the same water problems as its hemispheric neighbors to the south.

One partial exception is the fact that virtually the entire population of the United States is served with healthful drinking water supplies and adequate sanitation services. Yet, the aging of public water supply systems, the continuing emergence of contaminants that can threaten domestic water supplies, the inadequacy of some rural sanitation systems, and the looming need to update and renew some urban systems means that even this problem must inevitably be on the U.S. water resources agenda. In spite of the fact that the challenges of providing adequate drinking water and sanitation manifest themselves in different ways in the United States, the menu of water problems throughout the countries of the Americas is quite similar.

The description of the water resources of the United States and the associated management problems that follows illustrates the commonality of water problems throughout the hemisphere. To be sure, differences from country to country are likely to be both of degree and extent. Similarly the regional variability of the water resource situation in the U.S. and the associated management problems tends to be manifested as differences of degree and extent. This lesson emerges for the sections of this contribution that follow. The characterization of water resources and management challenges is organized and discussed in five sections. First, the variability in water occurrence and the availability of supply across the nation. Second, current and anticipated patterns of water use in different regions.

Third, the state of water resources research in the United States and the extent to which research is likely to deliver the new science needed to address the challenges of the future. In the fourth and final section, the principal water management challenges facing the U.S. and the possibilities for successfully addressing those challenges.

2. The Occurrence and Availability of Water

The magnitude and timing of precipitation varies substantially from place to place across the country. In quantitative terms, precipitation levels are commonly divided into two general realms, demarcated by the 100th meridian. This is the line that separates the relatively moist eastern portion of the country, (where rainfall generally exceeds 500 mm annually), from the relatively dry western portion of the country, (where rainfall is generally less than 500 mm annually.) Annual precipitation levels of 500 mm are thought to be particularly significant because that is the minimum level under which rainfed agriculture can be conducted profitably over time. In areas where precipitation is less than 500 mm, supplemental irrigation is almost always required if agriculture is to be both productive and profitable.

As shown in FIG. 1, the climates of the moist eastern region of the country, and the dry western region, are quite different.

Annual precipitation in the eastern regions averages between 650 mm and 1500 mm annually. The region is dominated by three climate types: a humid subtropical climate, which is found in the mid- and southeastern portion; a humid continental climate with warm summers which is found in the mid- and near northern portions; and a humid continental climate with cool summers which is found in the far northern portions.

The dry western region has more variability both in terms of the magnitude of precipitation and the number of climate types. Precipitation ranges from less than 125 mm annually in the arid southwestern desert to more than 2500 mm annually in the rainforests of the Pacific Northwest. With the exception of the moister northwest and the high mountain ranges, precipitation throughout most of the western region tends to be between 250 and 500 mm annually.

Three climate patterns are the rule. They are: mid-latitude desert climate with very low rainfall; semiarid steppe climate which occurs over the western plains and the Great Basin; and alpine climate which is manifest in the higher mountain ranges. To these three must be added two climate types which are found in proximity to the west coast. The southern west coast that includes much of California has a Mediterranean climate while the more northerly reaches have a Marine West coast climate with large amounts of rainfall. Rainfall amounts and seasonality in this latter region stand in contrast to the remainder of the western region. Precipitation varies temporally as well as spatially. Some climates vary interannually. Thus, for example, the

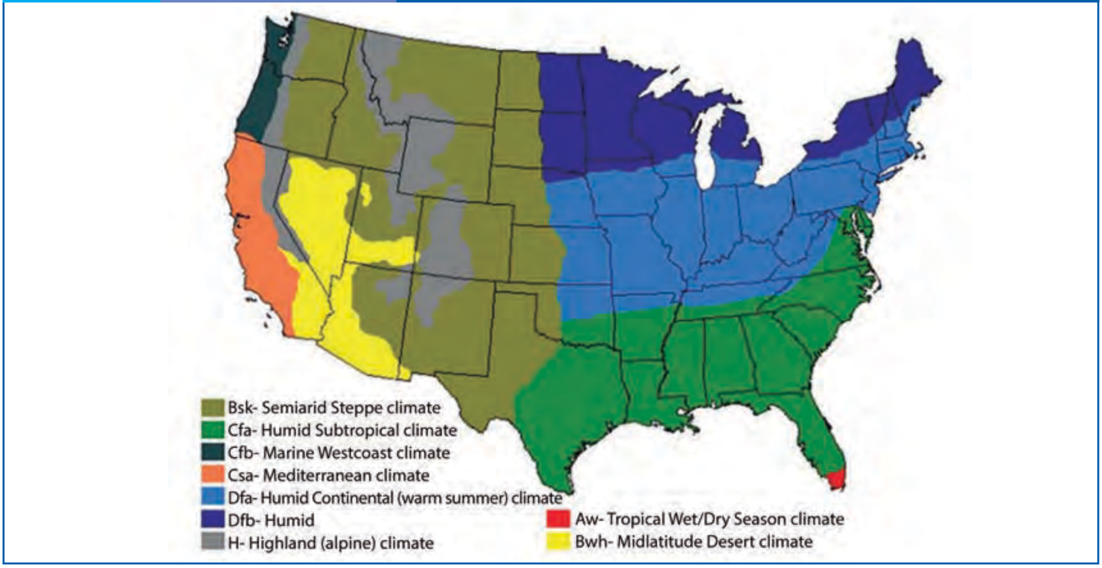


FIG. 1. Climate Zones of the Continental United States.

Mediterranean climate of the southern west coast is characterized by a rainy period from November to April and a dry period from May through October. The climate of the arid southwest entails two wet seasons - a winter season and a monsoon season from late July to early September when more than 90% of the precipitation occurs. By contrast, the mid-latitudes of the eastern part of the country tend to have a moderate climate with rainfall in relatively equal amounts in all seasons. The southeastern U.S. is subject to hurricanes that can bring enormous amounts of precipitation that introduce large distortions into local patterns of precipitation.

In addition to annual variations which are characteristic of specific climate types, periods of flood and drought have been present throughout recorded history. Thus, virtually every region of the country tends to experience recurring droughts that can range from moderate to severe. Similarly, flood events recur periodically, and those too range from moderate to severe.

The extent of precipitation which falls as snow can also be important in a temporal sense. Significant areas of the arid west rely on spring snowmelt as an important source of water. In places where snow is common in the winter months, spring snowmelt tends to skew the impacts of precipitation toward the spring. Precipitation is generally partitioned among evaporation, deep percolation and runoff. The quantities of surface supplies available to support consumptive and instream uses are a function of run-off which is some fraction of precipitation. That fraction is dependent upon a host of factors which differ from place to place and time to time. However, precipitation provides a reasonable approximation of the relative magnitudes of available surface water in different regions of the country. As illustrated in FIG. 2, nationwide surface water accounts for approximately 77% of total freshwater diversions exclusive of those used for thermoelectric production. The remaining 23% comes from ground water resources.

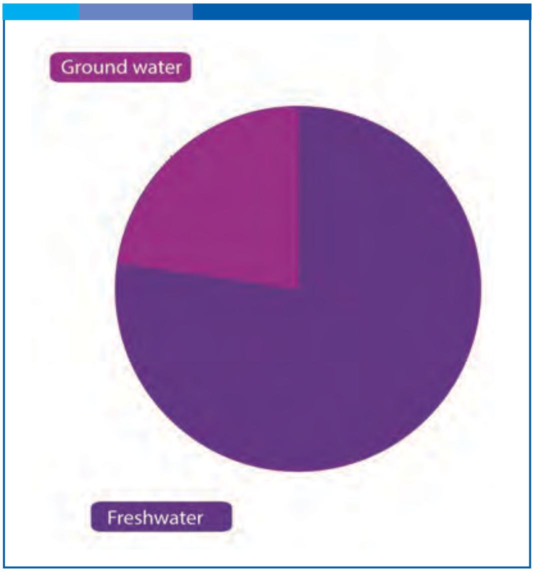


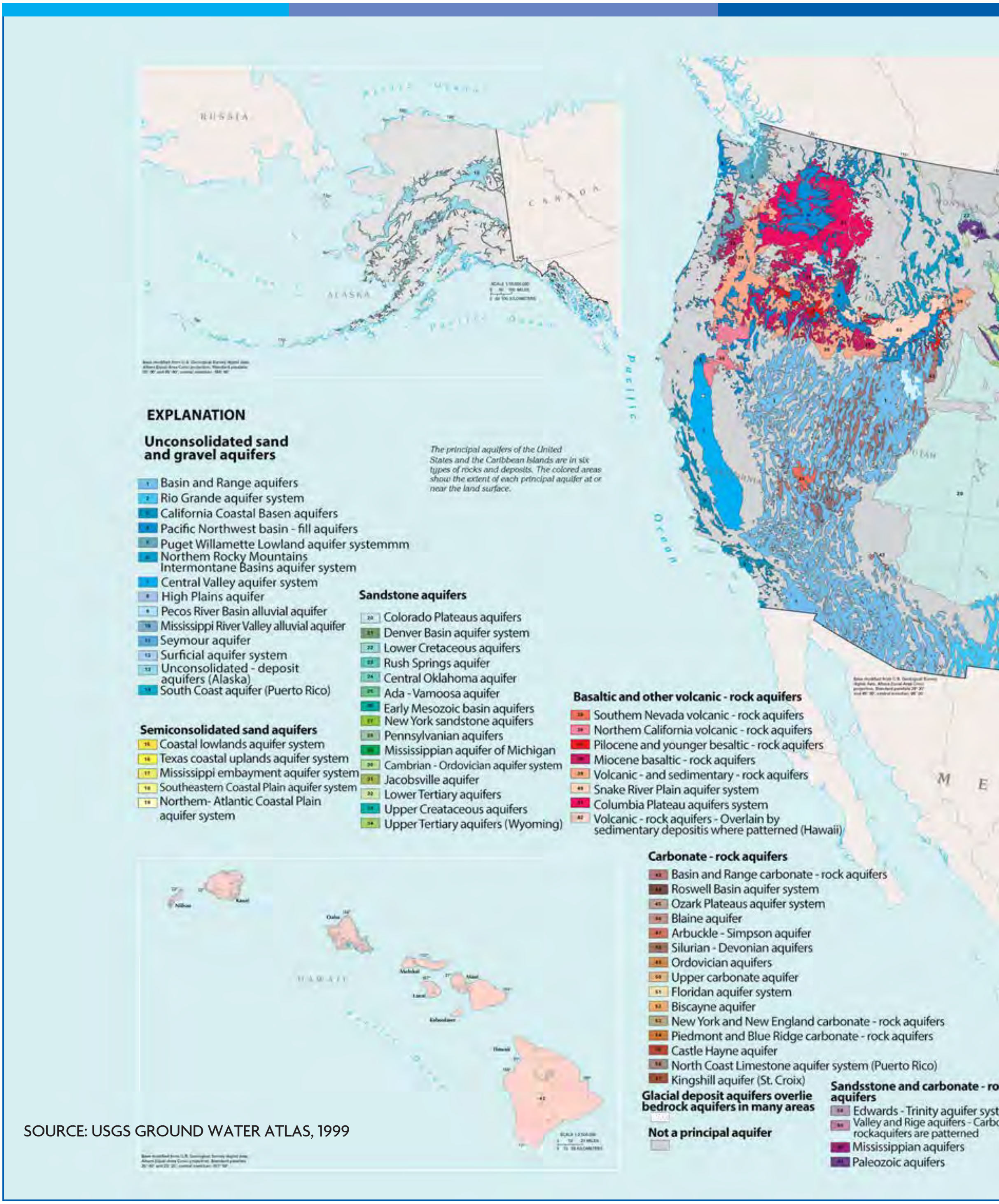
FIG 2. Sources of Water Supplies in the United States

The United States has substantial ground water resources and virtually no region of the country completely lacks ground water. FIG. 3 shows the location of nation's principal aquifers or ground water bodies. The importance of ground water lies in the fact that it is a significant source of drinking water in every state. Ground water is also an important source of agricultural water in the arid and semi-arid western states where irrigation is practiced extensively. Moreover, the quantities of ground water available in storage are significant and can provide extra supply on a temporary basis if surface supplies are not available. Thus, ground water can provide important protection in times of drought when surface supplies are not available in the usual quantities. (Alley, Reilly and Franks, 1999). The fact that ground water is stored in aquifers and does not respond directly, in terms of recharge, to shortfalls in precipitation means that it tends to be readily available, at least over the short run in times of drought. In addition, dewatered pore space in the nation's aquifers provide very significant storage capacity (Alley, Reilly and Franks, 1999). The health of the nation's ground water is a matter of some concern. Ground water overdraft threatens the sustainability of available quantities of water while ground water contamination, especially with toxic waste, threatens its quality. As a general rule, the quantity of water available for extraction on a long term basis can be no more than the annual rate of recharge. When more water is extracted than is discharged, the ground water is said to be overrated. Persistent overdraft cannot be sustained indefinitely because overdraft results in the decline in the level of the water table as more water is extracted than is recharged. Persistent overdraft means that ultimately the water table will drop to a point where at least some subset of the extractors can no longer extract economically and extractions will decline.

Persistent overdraft leads to a number of problems. First, in most areas surface water and ground water are linked. Where this occurs, reduction in water tables will tend to accelerate the rate of recharge at the expense of surface water flows. Second, land subsidence, or a settling of the land surface, is frequently the result of persistent ground water overdraft. Galloway, Jones and Ingebritsen (1999), report that more than 80% of the land subsidence in the United States is attributable to ground water overdraft. Third, overdraft can lead to significant declines in ground water quality. Most commonly this happens when coastal aquifers are overdrawn and sea water intrusion results. Quality declines can also be experienced in inland aquifers where good quality water is extracted from the upper layers of the aquifer, thereby allowing poor quality, often saline waters to be drawn upward.

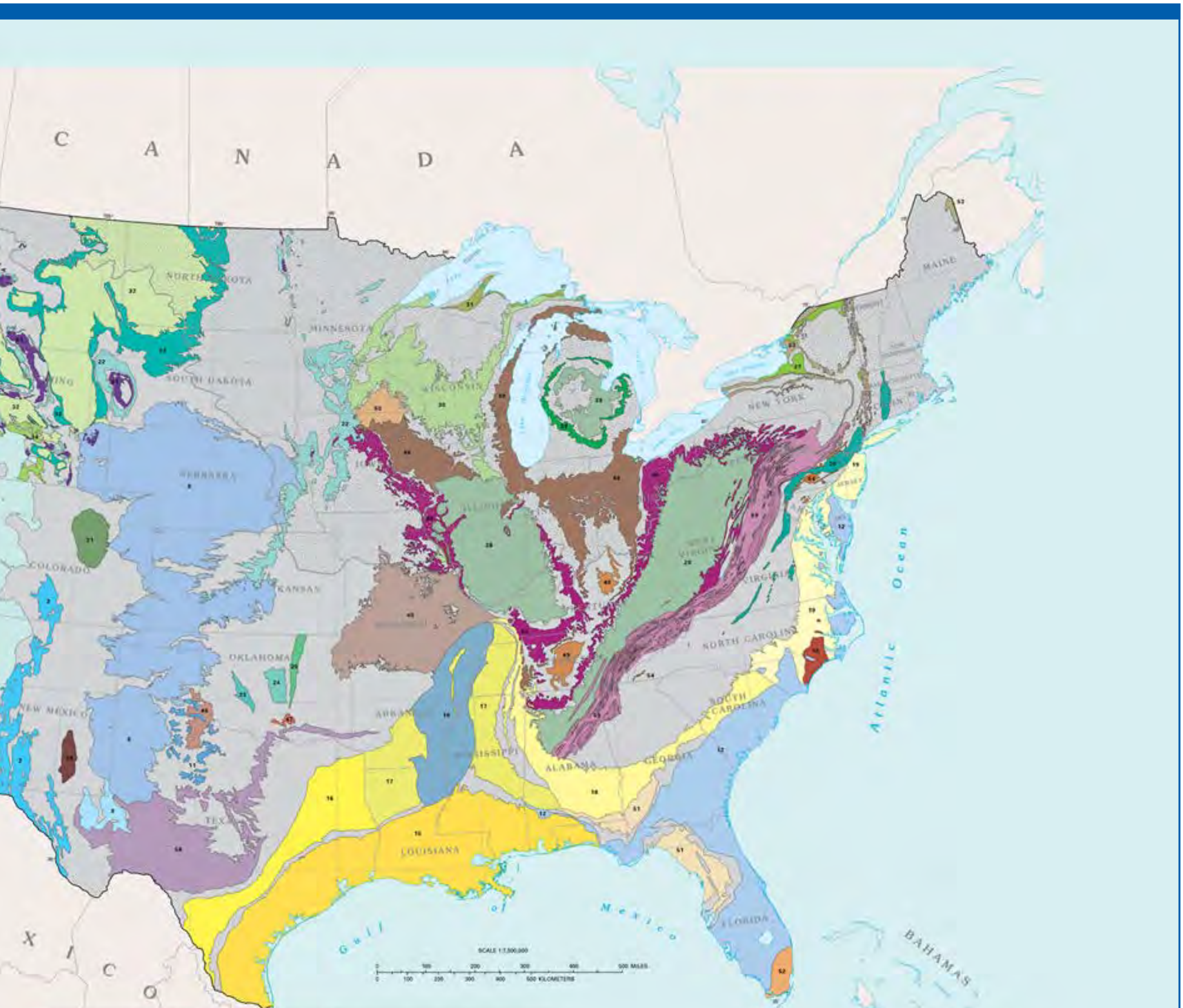
Overdraft occurs to some extent in all regions of the U.S. Along the Atlantic Coastal Plain it has had significant impacts on surface water flows. In West Central Florida and along the Gulf Coast, sea water intrusion has been significant. The High Plains overlie the famous Ogallala Aquifer which holds enormous volumes of water but recharges very slowly and in some places not at all. On the southern High Plains the drawdown has had significant economic impacts on agriculture in the region which has been supported historically by ground water. The inland Pacific Northwest has also been subjected to substantial ground water drawdown. Again, overpumping by agricultural users has been the cause. Finally, there has been substantial ground water overdraft in the southwest desert and in rural aquifers in California. In all of these instances efforts to attenuate the overdraft have been only partially successful. As a result, the problem of persistent overdraft continues to threaten the sustainability of aquifers in many regions (Alley, Reilly and Franks, 1999; U.S. Geological Survey, 2003). The other major threat to the sustainability of ground water resources in the U.S. is ground water contamination. In addition to the salt water intrusion which is mainly caused by overdraft, ground water can be contaminated either through land surface/aquifer interactions or surface water/ground water interactions. Land surface/ground water interactions are dominated by non-point source discharges. In irrigated areas, percolating waters-sometimes attributed to overirrigation-can carry pesticide, herbicide and other chemical residues into ground water. Similarly, livestock operations can lead to aquifer contamination with excessive nitrogen and other contaminants. Toxic wastes which were historically disposed of underground or in landfills of various sorts pose a particular problem. In many areas well-head regulations have help to reduce contamination but to date non-point source pollutants remain very difficult to control.

Surface water/ground water interactions can also damage ground water quality by carrying pollutants in the surface water to ground water through surface ground water interactions. Microbial contamination frequently can occur in this way if the overlying surface waters are badly polluted to begin with. Point source contaminants in surface waters have been regulated reasonably effectively by both national and state governments but non-point source contaminants in surface supplies remain a problem. There are two important principles that govern the regulation of ground water contamination. First, it is virtually always cheaper to prevent ground water contamination in the first place than it is to clean it up after the fact. Second, ground water tends to move much more slowly than surface water and frequently is not in contact with light. The result is that the self cleansing properties of ground water, including dilution, are less effective to those of surface waters. (Alley, Reilly and Franks, 1999).



SOURCE: USGS GROUND WATER ATLAS, 1999

FIG. 3. "Nationwide Map of Principal Aquifers"



NATIONWIDE MAP OF PRINCIPAL AQUIFERS

The distribution of the principal aquifers of the United States, Puerto Rico, and the U.S. Virgin Islands is shown in **figure 4**. The aquifers shown on the map are the shallowest principal aquifers; some are underlain by other productive aquifers, whereas others are overlain by minor aquifers. For example, the Mississippi River Valley alluvial aquifer overlies aquifers that are part of the Mississippi embayment aquifer system from southeastern Missouri to northeastern Louisiana, and also overlies aquifers that are part of the coastal lowlands aquifer system in east-central Louisiana. Local stream-valley alluvial aquifers that yield small to large amounts of water are in the valleys of many major streams that cross principal aquifers, but the stream-valley aquifers are not mapped on **figure 4** because of the map scale. Many of the principal aquifers are overlain by confining units and extend into the subsurface beyond the areas shown on the map.

The nationwide aquifer map was constructed by juxtaposing the regional maps of principal aquifers from the descriptive chapters. Regional maps for some chapters might show more detail than the nationwide map because minor aquifers that are important local sources of water were mapped in some States. On the nationwide map, however, such local aquifers are included in a category called "not a principal aquifer," along with confining units that might be mapped separately in some descriptive chapters. However, productive aquifers might underlie parts of the area mapped in this category: for example, the prolific Floridan aquifer system underlies the areas mapped as "not a principal aquifer" in the Coastal Plain of Florida, Georgia, and Alabama. Also included in this category are low-yielding aquifers that extend over large areas, such as those in the fractured crystalline rocks of the Appalachian and Blue Ridge region of the eastern United States.

Large areas of the eastern, northeastern, and north-central parts of the Nation are underlain by crystalline rocks. These igneous and metamorphic rocks are permeable only where they are fractured and generally yield only small amounts of water to wells. However, because these rocks extend over large areas, large volumes of ground water are withdrawn from them, and, in many places, they are the only reliable source of water supply. Accordingly, the crystalline rocks of northern Minnesota and northeastern Wisconsin, northeastern New York and the New England States, and the Piedmont and Blue Ridge Physiographic Provinces that extend from eastern Alabama to southeastern New York are mapped as aquifers in the Atlas chapters that describe those areas. Because the crystalline rocks have minimal permeability, they are not mapped as principal aquifers on **figure 4**.

In the north-central and northeastern parts of the conterminous United States, numerous local productive aquifers are in glacial deposits of sand and gravel. The map scale of the nationwide map is too small to allow individual aquifers in these glacial deposits to be shown. The general distribution of the glacial deposits is indicated by the dot patterned area on **figure 4**, and the locations of the principal bedrock aquifers that underlie them are mapped in the figure. These bedrock aquifers are used primarily where glacial-deposit aquifers are thin or yield little water.

The principal aquifers mapped in **figure 4** are in six types of permeable geologic materials: unconsolidated deposits of sand and gravel, semiconsolidated sand, sandstone, carbonate rocks, interbedded sandstone and carbonate rocks, and basalt and other types of volcanic rocks. Rocks and deposits with minimal permeability, that are not considered to be aquifers, consist of intrusive igneous rocks, metamorphic rocks, shale, siltstone, evaporite deposits, silt, and clay. There is, thus, a direct relation between permeability and type of geologic material. For this reason, the aquifers mapped in figure 4 are categorized according to their general geologic character. Each category is described and illustrated in the following sections of this report.

3. Water Use

Water use in the United States is usually counted in terms of combined withdrawals from both surface and ground water.

Total daily withdrawals average about 1.5 X 1012 liters. As shown in FIG. 4(a) below 80% comes from surface water and 20% from ground water. FIG. 4(b) summarizes the fact that 84.8% comes from freshwater sources while 15.2% from saline. (Saline water is used for cooling and for some industrial application). Finally, FIG. 4(c) shows approximately 77.4% of fresh water comes from surface supplies with the remaining 22.6% coming from ground water.

The practices of accounting for use as withdrawals creates some confusion because it fails to distinguish between water that is consumptively used and water that is returned to the stream and may be used again. Nevertheless it is the primary form in which the data are available. In terms of withdrawals, the two largest users of water are for irrigation which accounts for 31% of withdrawals and thermoelectric power production which accounts for 49%. There are two significant differences between these uses. First, a very high proportion of irrigation withdrawals is used consumptively by the crop itself, and return flows to both ground and surface waters, if any, tend to be quite modest. By contrast, thermoelectric water is used for

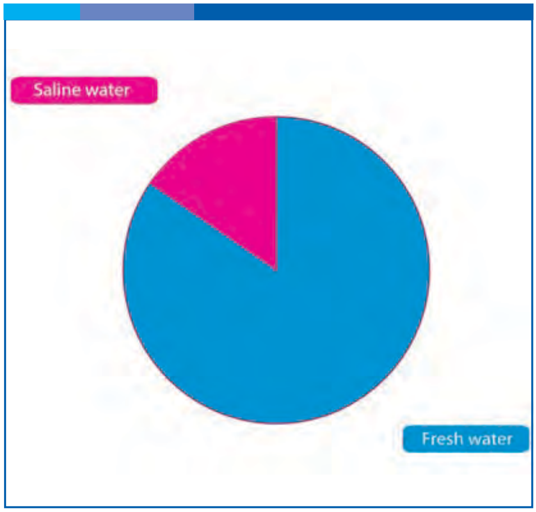


FIG. 4B. Withdrawals are 84.8% from Fresh Water and 15.2% from Saline Water

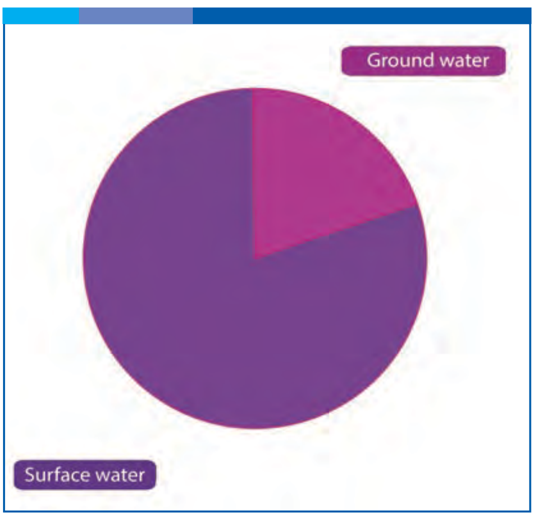


FIG. 4A. Total Fresh and Saline Water Source

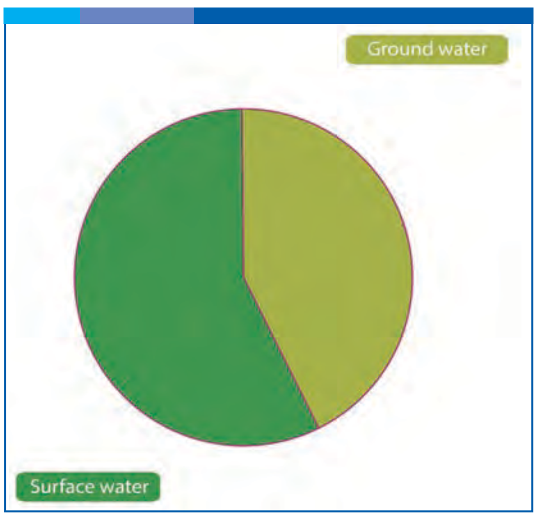


FIG. 4C. Fresh Water by Source

cooling purposes and a very small proportion of it is used consumptively. Most is returned to the river. A second important difference is that all irrigation withdrawals are freshwater while some withdrawals for thermoelectric are saline waters. It should also be noted that the great majority of thermoelectric uses occur in the eastern half of the country (hydroelectric power predominates in the west) while the great majority of irrigation water use occurs in the west where irrigated agriculture is predominant. Other uses are shown together with thermoelectric and irrigation in FIG. 5 below.

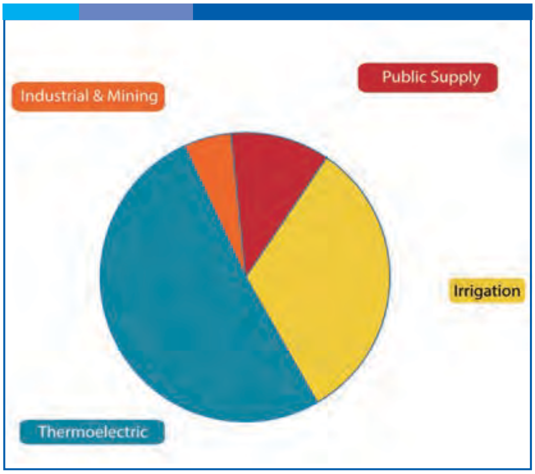


FIG. 5. Water Uses By Sector

The most recent year for which data are available (1995) indicates that in the aggregate, consumptive use equaled 25% of total withdrawals. This figure can be quite misleading, however, since the withdrawals for thermoelectric cooling account for nearly half of all withdrawals, yet only 1.95% of those withdrawals are used consumptively. Consumptive use in irrigated agriculture, by contrast, is a little over 60% of the water withdrawn for agriculture.

In geographic terms, the four largest water using states are California, Texas, Idaho and Florida. Together they account for approximately one-fourth of the total water withdrawals in the United States. California topped all states with the largest withdrawals of any state. California withdrawals accounted for 11% of the national total and more than three quarters of those withdrawals were devoted to irrigation. Texas ranked second with about 7% of the national total. In Texas, water is used predominantly for irrigation and thermoelectric power production. About 33% of all freshwater withdrawals are devoted to irrigation with 40 percent devoted to thermoelectric power. In addition, a little more than 60% of the saline water withdrawals were for thermoelectric power. Idaho ranked third and 85% of its withdrawals went to irrigated agriculture with another 13% going to aquaculture. Idaho's withdrawals were all freshwater and accounted for nearly 5% of the national total. Florida's freshwater withdrawals were allocated mainly to irrigation and public supply but total freshwater withdrawals were significantly smaller than saline water withdrawals which were used almost exclusively for power plant cooling (Kenny, Barber, Hutson, Linsey, Lovelace and Maupin, 2009).

The patterns of withdrawals and use in these four states that account for a quarter of the nation's withdrawals mirror generally the patterns found across the nation. Water for irrigation dominates in the western states as illustrated by California and Idaho and partly by Texas. Western states tend not to use large quantities of cooling water because they rely on hydroelectric power generation and, as a result, have small demands for cooling water in thermoelectric generation. Thus, these western states tend to use very small amounts of saline water. Only about a quarter of California's withdrawals are saline and Idaho has none at all. Texas has significant demands for cooling water which is the largest single use. Most of these demands for cooling are met with freshwater, however. Florida is generally representative of Southeastern and Middle Western states. 65% of its withdrawals are for thermoelectric cooling water and only 16% for irrigation which is used to supplement normal season rainfall. Patterns of use in most states, then, tend to be driven in part by available water supplies and also by the high productivity of irrigated agriculture in the west and the relative absence of good hydroelectric generating sites in the east.

4. Water Resources Research in the United States

As a general rule, in the United States, the national government is responsible for the governance and regulation of instream flows and instream uses while the states typically govern and regulate consumptive use.

Thus, most rights to divert water and use it consumptively are granted and regulated by the states. The federal government not only regulates instream uses such as navigation, environmental uses and flood control, it is also responsible for those aspects of water resources management that have widespread benefits and that are difficult to withhold from "consumers" if they are unwilling to pay. These so-called "public goods" include mainstream flood control, aquatic biodiversity and water resources research. Water research began in the 19th century at about the same time as the discovery of bacteria. Much of the early water research of the first decades of the 20th century focused on public health problems. There was some early work on pollution, and beginning in the mid-1930s, some work on flood control as federal legislation created new federal obligations for flood control. Science in general became much more important during and immediately after World War II and water science received a major boast from the Senate Select Committee on Water Resources which recommended a much larger role for the federal government in the conduct of water research. Authorizing legislation and funding followed in short order and the federal water research establishment began to grow (National Research Council, 2004).

Although the decades of the 1960s and 1970s were times of growth in water resources research, federal support of that research began to stagnate in the 80s and 90s and has remained static through the first decade of the 21st century. A review of the federal water research enterprise shortly after the turn of the century revealed that it was beset with a number of problems even though the total value of resources available to support water research, when adjusted for inflation, had remained quite stable. The evidence shows that total federal spending on water resource research was around US$700 million (in constant 2000 dollars) in the 70s and was at that level during the first years of the 21st century. Although there is controversy over whether this is an adequate amount, spending on water research has remained relatively static when compared with the growth in population, gross domestic product and total federal outlays. Yet, perhaps more importantly there are other symptoms that suggest that the federal research enterprise is not in particularly good shape to meet the challenges which lie ahead (some of those challenges are described in the next section).

Many Actors, Little Coordination: Water resources research is conducted by no less than ten federal agencies. It is fragmented, lacks strategic coherence and is susceptible to unneeded duplication. Five of the federal agencies, listed in Table 1 below, account for almost 88% of total funding though no agency contributed more than 25% of the funding.

Table 1. Federal Agencies with Major Role in Supporting Water Research

Agency (Abbreviation)	Percentage Federal Water Research Budget, in 2000
U.S. Department of Agriculture (USDA)	17%
U.S. Geological Survey (USES)	18%
National Science Foundation (NSF)	22%
U.S. Department of Defense (DOD)	15%
U.S. Environmental Protection Agency	15%
Source: (NRC, 2004)	

There are an additional five agencies whose support levels total approximately 12%. They are listed in Table 2 below. The problem here is not with the alignment of agencies within the two categories but with the fact that there are many agencies independently carrying out programs of water research and supporting such research at the nation's Universities. There is no mechanism for setting national water research priorities. There is no process through which aggregate performance of the federal government in the water research area can be assessed periodically and revised to ensure that the nation is getting the most for its water research dollar (National Research Council, 2004).

Table 2. Federal Agencies with Minor Role in Supporting Water

Agency (Abbreviation)	Percentage Federal Water Research Budget, in 2000
U.S. Department of Health & Human Services (DHSS)	1%
U.S. Bureau of Reclamation (USAR)	2%
National Oceanic & Atmospheric Administration (NAA)	4%
U.S. Department of Energy (DOE)	4%
National Aeronautics & Space Administration (NASA)	2%
Source: (NRC, 2004)	

The pattern of research topics in the federal portfolio fails to reflect modern priorities. The emphasis and funding support provided to the various research subjects does not reflect current topical research priorities. Specifically, research on water law, water demand and other institutionally relevant topics are now funded at levels significantly below the levels they were funded at 30 years ago. Moreover, water supply augmentation and conservation fall into the same categories. It is clear that substantial new investment must be made in these categories if the challenges of the future are to be. The current water research portfolio is heavily weighted toward short-term research. If the nation is to be prepared for the problems that it will face a decade or two hence, the portfolio will need to devote a substantial proportion of its funding to research focused on longer term challenges (National Research Council, 2004).

What is needed is a coordinated, strategic approach to the national water research effort which will set strategic goals, prioritize the research needed to help achieve those strategic goals ensuring that the topical balance is appropriate to the modern problems and those that can be foreseen on the horizon, allocate the limited research funds to the priority areas of research, and conduct honest retrospective e analyses to ensure that the funds are spent efficiently and yield the results that are sought. To do less means that the United States and those that rely on its research enterprise will be less well equipped to meet the challenges of the future than they could be.

5. Major Water Issues Facing the U.S.

The United States faces many water issues and challenges. Some of these are site specific or regional in nature. Others will manifest themselves almost everywhere in the nation and these present urgent challenges that will have to be addressed on a continuing basis. There may be as many as several dozen such issues and a discussion of the relative urgency of each is beyond the scope of this contribution. Rather, six compelling issues have been selected for further discussion and they provide both a sense of the diversity of water resource issues facing the United States as well as the case for urgency in dealing with them.

Managing Water Scarcity.

Water scarcity is pervasive in the United States and new methods and processes must be found to aid in managing scarcity. The cities of the arid and semi arid southwestern U.S. are the fastest growing cities in the country. These include Denver, Phoenix Albuquerque, Las Vegas and Los Angeles. All will require additional supplies to support anticipated population growth and yet it is unclear where that water will come from. The current flow regimes of the Missouri River jeopardize three species which have been declared endangered. The recommendations for improving the habitats of these species would require increases in river flows during the spring and declines during the summer. The summer declines would adversely impact the navigability of the river and make it both more difficult and more expensive to ship the substantial agricultural harvest in the basin. The situation has resulted in an impasse because there it is not possible to improve the habitat of the three species in question while protecting the historical navigability of the Missouri River (National Research Council, 2002).

The situation in the Klamath Basin of southern Oregon and northern California is quite similar. There irrigation water was cut off so that river flows and lake levels could be manipulated to benefit several endangered species. Conflict emerged when irrigators and scientists alleged that the science behind the decision to cut off irrigation flows was flawed. An impasse of sorts emerged here as well because there was insufficient water to serve both the perceived environmental need for water and the irrigation contracts (National Research Council, 2003).

The manifestations of scarcity are not confined to the western regions of the country. Glennon (2002) documents examples from across the nation in which excess ground water withdrawals have caused the drying up of streams and rivers and a cascade of social conflicts, economic hardship and environmental degradation. In many cases, the problem is worsened because existing legal systems do not recognize that surface and ground water are interconnected. The waters of the Potomac River were the focus of a dispute between Maryland and Virginia in the early years of the 21st century. Ultimately this dispute had to be resolved by the U.S. Supreme Court. And there is extant another dispute between the states of Georgia, Alabama and Florida that focuses around the efforts of Atlanta, Georgia to secure sufficient water to support anticipated population growth. The manifestations of scarcity are no longer restricted to dry western regions but are now part of the water management picture nationwide. New methods will have to be found to resolve the resulting conflicts and to help ensure that the nation gets optimal return from an increasingly limited water supply.

Protecting the Nation's Drinking Water Supplies.

Over the last 100 years the U.S. has made enormous investments in its water treatment and distribution system. The result has been that the aggregate water supply has been among the safest, most reliable and most healthful in the world. Yet there are two distinct threats which will have to be dealt with in the future. The first, focuses on the list of new and potential contaminants which threaten the raw water supplies on a continuing basis. The second focuses on an aging water and sanitation infrastructure which will have to be largely rebuilt in the coming century. As economic development continues, the appearance of new chemicals and their residues will likely accelerate. Such chemicals are developed for specific purposes and frequently confer large benefits on society. Yet, at the time they are introduced, their behavior and fate in the environment are unknown. There is a clear propensity for raw water supplies to be contaminated not just by newly developed chemicals but with chemicals that have been heavily used in the past and may not have been properly disposed of.

Thus, for example, chemicals ranging from the residues of pesticides and fertilizers have appeared in ground water some decades after their use began. Over the last years, a chemical used in the manufacturing processes for munitions, rocket fuels and fireworks has appeared in California's ground waters. This chemical is suspected of being a human carcinogen and is known to interfere with human thyroid hormone production. These are not isolated examples. Chemicals of all sorts - new and old - have appeared and will continue to appear in the nation's ground and surface water. Methods to detect these chemicals in the environment early on and to develop technologies for treating and removing them from drinking water supplies will be sorely needed. Ideally, it would be desirable to further the development of screening protocols which would allow an early assessment of how new chemicals are likely to behave in the environment and characterize the possibility for contamination. The second threat to the integrity of the nation's drinking water supplies is the aging infrastructure. In the coming decades there will be failures of urban distribution systems, some of which are well over 100 years old. Drinking water treatment plants will have to be replaced, and will need to be designed in ways that will permit them to adapt to new challenges in maintaining drinking water quality. It is not even clear that simply replacing existing systems makes sense. The need to replace distribution systems under miles of paved urban areas points to the importance of considering more decentralized types of systems which serve well defined communities or even individual dwellings should be examined. There is also the very real issue of how the replacement of such systems can be financed. Early estimates of total costs are staggering.

Can an Effective Water Policy be made?

There is much evidence that many federal water policies are either ineffective or only partly effective. Thus, for example, many hectares of wetlands have been lost to development over the years in spite of the fact that wetlands are enormously productive biologically and provide all manner of environmental services. In 1990 the federal government enacted a policy that required that there be no net loss of wetlands. It required that there had to be mitigation where wetlands were destroyed or modified. The evidence shows that despite the requirement that more than one hectare of wetlands must be restored for each hectare destroyed; only 70% of the required land area was actually restored or created (National Research Council, 2001). In addition, many of the mitigation efforts were not monitored and there was full compliance with only about half the permits issued. This is attributable in part to the lack of adequate scientific information on which to base mitigation efforts. Specifically, restoration ecology is not currently well enough understood to allow such efforts to go forward.

There are a number of other areas where the making of policy is hampered by the lack of adequate scientific information. These include: 1) Treatment of drinking water supplies. The policies required to govern adequate drinking water will require additional science on the fate and transport of new chemicals in the environment as well as information about the effectiveness of new and existing treatment technologies in removing harmful and potentially harmful contaminants. 2) The use of water in agriculture. Agriculture is a major consumptive user of water and is seen by many as the supplier of last resort to support new, high valued uses. Yet the demands for agricultural products will continue to grow as the world's population grows. In addition, agricultural water management contributes to the pollution of ground and surface water and to the erosion of some lands.

These non-point sources of contamination have been extremely difficult to regulate effectively. 3) The maintenance and preservation of aquatic habitats. There is insufficient knowledge about the quantities of water to support aquatic habitats. There is also insufficient knowledge about the relationship between aquatic and terrestrial habitats. Without better knowledge in these areas it will be difficult to devise policies which can protect and enhance environmental flows, amenities and services. 4) The management of floods and droughts will require additional scientific information if they are to be managed effectively. This is particularly so because of the specter of global climate change which likely will lead to a higher frequency of extreme events.

Adapting Water Management Systems to Global Climate Change.

The specter of climate change promises not only changes in the frequency of extreme events such as floods and droughts, but also fundamental changes in the availability of water as precipitation and how natural rates of demand (such as evapotranspiration) respond to altered climatic circumstances. Although substantial resources have been expended for basic climate change research, there has been little funding and little effort to develop better methods for managing water resources in a more uncertain and less stable environment. The management of water resources has been identified as one of the weakest elements of climate change integrated assessments. (National Assessment Synthesis Team, 2001). At a minimum, climate change will require that more attention has to be paid to uncertainty over the availability of water supplies across time and space. The development and implementation of risk management strategies will be critical in coping with the many changes that climate change could bring, both those that can be predicted and those that are uncertain. Urban water supply systems may be vulnerable as will existing agricultural systems. What will be required is the development of water management technologies and techniques which permit water to be managed far more adaptively than has been the case in the past. Thus, for example, investing in enormous new surface water storage capacity makes little sense when it is unclear how much, if any, additional water might be available to store. A more adaptive strategy would be to rely on empty pore space underground as a storage medium. This latter strategy has the advantage of being much cheaper since evaporative losses that are associated with surface water storage facilities would be avoided. In addition, underground storage can be utilized, if needed, with relatively short lead times and thus is better adapted to managing uncertain water availability and water demands.

Managing Regional Water Systems.

Throughout the U.S. there are numerous examples of large scale water systems that have been heavily man-modified which are now under intense pressures from the need to address growing demands for water even while protecting the aquatic ecosystems which supply those demands. There are two major examples. They are the Sacramento-San Joaquin River/ San Francisco Bay Delta in California and the Greater Everglades Ecosystem in southern Florida. These are considered in turn. The Sacramento-San Joaquin/San Francisco Bay Delta is one of the most man-modified deltaic systems in the world. Historically, most of it was a wetland which was drained and channeled to permit agriculture to be practiced on some 60 islands that were reclaimed. Subsequently, the Delta was used as a transport facility from which water flowing from the north was extracted and pumped southward to serve agricultural and urban demands. Although the Delta has been subject to extensive modification it still serves as a habitat for a highly diverse biota some of which has been introduced. A number of the species found in the Delta have been listed as rare and endangered. The agencies charged with managing waters there must find a way to protect and enhance those species while continuing to supply water contractors to the south (National Research Council, 2010; Lund et al. 2010).

At its heart, the problem with water management in the Delta is a problem of managing scarcity. There is no evidence to suggest that the environment of the Delta can be reasonably protected while the reliability of water exports to the south can be increased. Yet, the ecosystem is so complicated and the interrelationships between water demands and flows on the ecosystem so poorly understood, that it is not at all clear what strategies have some positive chance to be workable. Clearly, the approach must be one of adaptive management. Equally clearly, the approach must recognize that the fundamental problem is scarcity and the days when all uses can acquire additional water without interfering with other uses are over. The sheer complexity of the situation is the overriding factor, however, and it is unclear even whether systems this complicated can be susceptible to effective management. The Greater Everglades Ecosystem in central and southern Florida is a wetland system unlike any other in the world. Over the years there have been major encroachments on the system for the purposes of developing agricultural and suburban land and for the purposes of providing flood control to protect development in central and southern Florida. About a decade ago it became obvious that without extraordinary efforts the unique Everglades ecosystem would become so modified that it would be lost. Restoration plans are being prepared and debated, (National Research Council, 2008)

This situation is also fraught with complexity and uncertainty. Restoration of water flows which were previously modified for flood control purposes is at the heart of the restoration effort. Part of the problem is that water must be stored and the only available storage sites are subterranean limestone quarries. The feasibility of using such quarries is in question but even if that question can be favorably resolved, issues of restoration biology remain. It is unlikely that vast portions of the Everglades could be restored exactly to their original condition, so there are issues of what approximations are reasonable yet feasible for restoration purposes. The complexity and sheer size and diversity of the ecosystem means that ways will have to be found to manage large-scale risk and uncertainty. The costs of further restoration and modification of these two giant systems are enormous. There is some likelihood that even if sizeable investments are made, restoration goals cannot be achieved. There is simply not enough knowledge about how these large systems work and not enough understanding of all of the complex interrelationships. Yet, the management problems of the Sacramento-San Joaquin Delta and the Greater Everglades

Ecosystem are not unique. Solving problems that arise in connection with the management of this sort of very large, very complex water systems are likely to become the rule rather than the exception in the future. Solutions are likely to come incrementally and as the result of sophisticated schemes of adaptive management must be carefully devised and thoroughly vetted in advance.

6. References

1. Alley, William M. Thomas E. Reilly and O. Lehn Franks. 1999, Sustainability of Ground Water.
2. Resources. U.S. Geological Survey Circular 1186. Pp79
3. Center for Sustainable Systems, University of Michigan. 2010 . U.S. Water Supply and Distribution Fact Sheet. Publication No. CSS05-17.
4. Galloway, D.L. D.R. Jones and S.E. Ingebritsen, eds. 1999. Land Subsidence in the United States. U.S. Geological Survey Circular 1182. 179 pp.
5. Lennon, Robert. 2002. Water Follies: Groundwater Pumping and the Fate of America's Fresh Waters. (Washington, DC: The Island Press).
6. Kenny, J.F., N.L. Barber, S.S. Hutson, K.S. Linsey, J.K. Lovelace and M.A. Maupin. 2009. Estimated Use of Water in the United States in 2005. U.S. Geological Survey Circular 1344. 52 pp.
7. Lund, Jay R., Ellen Hank, William E. Fleenor, William A. Bennett, Richard E. Howitt, Jeffrey F. Mount , and Peter B. Moyle. 2010. Comparing Futures for the Sacramento-San Joaquin Delta (Berkeley, CA: The University of California Press).
8. National Assessment Synthesis Team. 2001. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change (Washington, DC: U.S. Global Change Research Program).
9. National Research Council. 2001mCompensating for Wetland Losses Under the Clean Water Act. (Washington, DC: The National Academy Press).
10. National Research Council. 2002. The Missouri Ecosystem: Exploring Prospects for Recovery.
11. (Washington, DC: The National Academy Press).
12. National Research Council. 2003. Endangered and Threatened Fishes in the Klamath River Basin: Causes of Decline and Strategies for Recovery (Washington, DC: The National Academy Press).
13. National Research Council. 2004. Confronting the Nation's Water Problems: The Role of Research (Washington, DC: The National Academy Press). pp. 310.
14. National Research Council. 2008. Progress Toward Restoring the Everglades: The Second Biennial Review (Washington, DC: The National Academy Press).
15. National Research Council. 2010. Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta. (Washington, DC: The National Academy Press).
16. U. S. Geological Survey. 1999. Ground Water Atlas of the United States
17. U.S. Geological Survey. 2003. Ground Water Depletion Across the Nation. USES Fact Sheet 1034-03. November

Embalse Clavellinos, Estado Sucre, Venezuela.
Photo: Dr. Ernesto J. González

Water Management in Venezuela

General Aspects

Ernesto J. González[1], María Leny Matos[2]

[1]Laboratorio de Limnología, Instituto de Biología Experimental de la Universidad Central de Venezuela
[1]Punto Focal Nacional de Venezuela - IANAS, Programa de Aguas

[2]Hidroven, Laboratorio de Plancton

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1. Introduction

Venezuela has abundant water resources, distributed in seven hydrographic systems and 16 hydrographic regions. The country accounts with more than 100 reservoirs, which have been built in order to satisfy diverse purposes: drinking and industrial water supplies, irrigation, flood control, recreation and hydroelectric power production.

So many anthropogenic activities are developed in Venezuelan hydrographic regions, which are affecting water quality of stream, lakes and reservoirs. Some of these problems are: eutrophication, pollution, lowered water flow, high water demand for watering, domestic and industrial uses, among others. In Venezuela, there are lots of regulatory standards and laws concerning with the water conservation and water resources management. There are many Institions related with water management and research in Venezuela, including Ministries, Governmental Enterprises, Universities and Research Institutes, among others. Some cases of practices of water resources management are also discussed.

2. Hydric Resources

Venezuela has abundant water resources, especially in the Southern region (Rodríguez-Betancourt & González-Aguirre, 2000). Volume of water resources are calculated in 1320 km^3 per year (Cañizales et al., 2006). The occupancy process of the National territory was characterized by a progressive population concentration on the Andean-Coastal arch of the country and, specifically, in the big cities located in North-Central area, which have less water availability (Rodríguez-Betancourt & González-Aguirre, 2000; Cañizales et al., 2006).

Water demand in Venezuela is associated to irrigation, industrial-urban uses, and electric power production (Rodríguez-Betancourt & González-Aguirre, 2000). Navigation, and recreation uses represent relatively minor demands with a non-consumptive character.
To satisfy water demand, a total of 110 reservoirs have been built in Venezuela (MINAMB, 2006), which serve for diverse purposes: drinking and industrial water supplies, irrigation, flood control, recreation and hydroelectric power production (González et al., 2004a; MINAMB, 2006; González et al., 2009a).

However, their misuse and human activities in their basins have generated several problems, among them: fish culture without a previous limnological evaluation (Infante et al., 1992; 1995), agrochemical pollution (Infante et al., 1992) and eutrophication (González & Ortaz, 1998; Ortaz et al., 1999; González et al., 2004b).

To treat or solve some of these problems, some remedial measures have been suggested (i.e., González et al., 2002; Estaba et al., 2006), as well as the creation of protected areas and regulatory standard issues for nutrient control in sewage (Gaceta Oficial, 1995), in order to protect the water bodies and their water quality.

The purpose of this study is to depict a general view and analyze some practices, laws and regulatory standards related with water management in Venezuela.

3. Venezuela in the World

Venezuela is located in the Northern region of South America, between 00° 38′ 53″ and 12° 11′ 46″ latitude N and between 58° 10′ 00″ and 73° 25′ 00″ longitude W (MINAMB, 2006), covering an area of 916,445 km^2. Venezuela is bordered to the North by the Caribbean Sea and the North Atlantic Ocean, to the East by Guyana, to the South by Brazil and Colombia, and to the West by Colombia.

Although Venezuela is entirely situated in the tropics, its climate varies from humid low-elevation plains, where average annual temperatures range as high as 28 °C, to glaciers and highlands (the "páramos") with an average yearly temperature of 8 °C. Annual rainfall varies between 430 mm^3 in the semiarid portions of the Northwest to more than 4,000 mm3 in the Southern region. Most precipitation falls between June and October (the rainy season or "winter"); the dryer and hotter remainder of the year is known as "summer", though temperature variation throughout the year is not as pronounced as in temperate latitudes (Gobierno en Línea, 2009). Venezuela has 24,127,351 of inhabitants (estimated for 2004), especially in the Andean and Coastal regions, with a mean density of 28.9 inhabitants per square kilometer.

Biogeographically, Venezuela is situated in the Neotropical region, which includes the Caribbean, Amazon, Guiana, and Andean Domains (Cabrera & Willink, 1980); therefore, the country has several altitudinal steps, several types of vegetation and fauna, and several and distinctive basins. In Venezuela, there can be distinguished 7 hydrographic systems: Caribbean Sea, Orinoco River, Gulf of Paria, Casiquiare – Río Negro, Esequibo River, Lake Maracaibo and Lake Valencia (FIG.1). Among them, Orinoco system is the most important, grouping 49 sub-basins that drain their waters to the main channel of the Orinoco River, which represents 94.436% of total drained volume in Venezuelan hydrographic basins (FIG. 2) (Rodríguez-Betancourt & González-Aguirre, 2000), and discharges its waters to the Western Atlantic. A particular system is Lake Valencia, which is an endorheic basin and receives water from tributaries originated in the South region of the North-Central Cordillera; this hydrographic basin represents only 0.029% of total drained water volume.

More recently, Cañizales et al. (2006) distinguished 16 hydrographic regions in the previous classification (FIG. 3): 1) Lake Maracaibo – Gulf of Venezuela, 2)

"Falconiana", 3) Central – Western (Tocuyo – Aroa – Yaracuy), 4) Lake Valencia, 5) Central (Tuy – Central Littoral), 6) Central – Eastern, 7) Eastern, 8) Central "Llanos" (lowlands), 9) Central – Western "Llanos", 10) High Apure, 11) Apure, 12) High Orinoco, 13) Caura, 14) Caroní, 15) Cuyuní, and 16) Delta. It is outlined that the least water drained areas of the country comprise the densest population areas, generating problems relating with multi-purpose water supply.

4. Reservoirs in Venezuela

At the end of 2006, Venezuela accounted with 110 operative reservoirs (MINAMB, 2006; 2007), distributed along the national territory and built for multiple purposes: drinking and industrial water supply, generation of hydroelectric power, watering, recreation. Ministry of Environment is the proprietary of national reservoirs and rules the functions of these water bodies through the General Directory of Hydrographic Basins, Directory of Studies and Projects and Directory of Operation and Maintenance of Environmental Sanity Works.

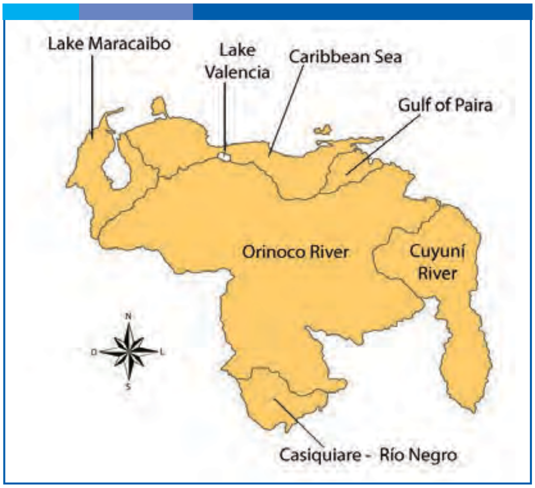

FIG. 1. Hydrographic Systems of Venezuela. Modified from MINAMB (2006).

Regional hydrological companies administrate the works dealing with conduction, treatment and distribution of potable water to the cities, while that National Institution for Rural Development manages watering affairs (MINAMB 2007).

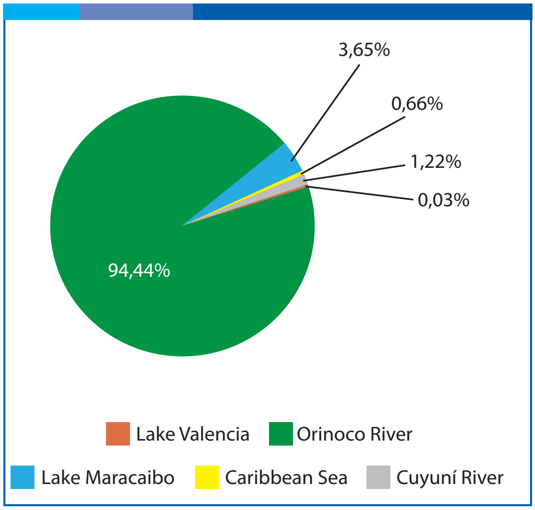

FIG. 2. Volume Percentages of Main Venezuelan Hydrographic Basins. From: Rodríguez-Betancourt & González-Aguirre (2000).

FIG. 3. Hydrographic Regions of Venezuela. Modified from MINAMB (2006)

Ministry of Environment grouped national reservoirs in eight circuits, according to their geographical locations, in order to plan their maintenance (Table 1).

5. Some Problems Related with Water Management

So many anthropogenic activities are developed in Venezuelan hydrographic regions, which are affecting water quality of stream, lakes and reservoirs. Some of these problems are: eutrophication, pollution, lowered water flow, high water demand for watering, domestic and industrial uses, among others.

Eutrophication:

Eutrophication has been reported for many water bodies in Venezuela, and many of them are used for drinking water supply to the main cities of the country. Caracas City and its metropolitan area (ca. 4,000,000 inhabitants) receive water from the Taguaza, Tuy and Guárico River basins, through the "Tuy River System" (González et al., 2009a), a complex web of pipelines which connects 9 reservoirs: Camatagua, Lagartijo, Taguaza, Quebrada Seca, Ocumarito, Taguacita, Macarao, La Pereza and La Mariposa. Only Lagartijo, Taguaza and Taguacita reservoirs are located in protected areas; the rest of them

Table 1. National Circuit of Reservoirs, Grouped According to Geographical Regions, for the Planning of their Maintenance. Modified from Minamb (2007).

Circuits	States	Reservoirs
Nº 1 (17)	Aragua, Carabobo, Miranda, Cojedes & Vargas	Suata, Taiguaiguay, Canoabo, Guataparo, Pao Cachinche, La Mariposa, Agua Fría, El Guapo, La Pereza, Lagartijo, Ocumarito, Quebrada Seca, Taguacita, Taguaza, Capaya, Pao La Balsa, Petaquire
Nº 2 (23)	Guárico & Anzoátegui (and Aragua)	El Pueblito, Guanapito, Guárico, Jabillal, La Becerra, Santa Rosa, Tamanaco, Taparito, Tierra Blanca, Tiznados, Vilchez, El Cigarrón, Coco 'e Mono, Camatagua, El Andino, El Cují, Guacamayal, La Estancia, La Tigra, La Tigrita, Santa Clara, Vista Alegre, San Miguel
Nº 3 (9)	Sucre, Monagas & Nueva Esparta	Clavellinos, El Pilar, Turimiquire, Guamo, Guatamare, La Asunción, San Juan Bautista, San Francisco de Macanao, San Antonio
Nº 4 (7)	Barinas, Portuguesa, Mérida & Trujillo	Masparro, Boconó-Tucupido, Las Majaguas, Las Mercedes, Las Palmas, Onia, Agua Viva
Nº 5 (19)	Falcón, Lara & Yaracuy	Camare o Pedregal, Cruz Verde, El Cristo, El Isiro, El Hueque III, Las Barrancas, Mamito, Mapara, Tocuyo de La Costa, Atarigua, Dos Bocas, Dos Cerritos, El Ermitaño, El Zamuro, Los Quediches, Cabuy, Cumaripa, Papelón, Durute
Nº 6 (6)	Zulia & Falcón	El Tablazo, Machango, Burro Negro, Socuy, Matícora, Tulé
Nº 7 (9)	Táchira & Mérida	Uribante, La Honda, Doradas, Las Cuevas, Camburito, Caparo, Borde Seco, La Vueltosa, Santo Domingo
Nº 8 (7)	Bolívar	Caruachi, Copapuicito, El Palmar, Macagua, Puente Blanco, San Pedro, Tocoma

are impacted by anthropogenic activities in their basins, reflecting the consequences of the eutrophication process: high phosphorus and nitrogen concentrations, high phytoplankton and macrophyte densities, cyanobacteria blooms, and bad water quality (Infante et al., 1992, 1995; Ortaz et al., 1999; González et al., 2003; González, 2008; González et al., 2009a).

Reservoirs from the North-Central region of the country are affected by human activities too. Pao-Cachinche reservoir, which is used for drinking water supply to Valencia, Maracay and San Carlos Cities (2,000,000 inhabitants) and for watering of agriculture fields, received tributaries with untreated wastewater from Valencia City (1.7 million inhabitants), and waste water from poultry and pig farms (González et al., 2004a; 2004b). Bad water quality and high phytoplankton density were common facts before the application of artificial destratification process (Estaba et al., 2006). Other reservoir, Suata, which is used for watering of the neighboring fields, received high concentration phosphorus load from its main tributary and the poultry farms that surrounded the water body. Total phosphorus concentration reaches up to 2400 µg/l, producing high biological productivity (González et al., 2009b).

Reservoirs from Venezuelan lowlands ("llanos") are impacted by the use of fertilizers in their neighboring lands, generating eutrophication problems (Infante et al., 1995; González, 2000). Cyanobacteria dominated phytoplankton community in most of them. Reservoirs from the Western region of Venezuela also showed eutrophication problems. Tulé reservoir is a shallow water body that is used for drinking water supply to Maracaibo City (ca. 3,000,000 inhabitants), and it showed low transparency and high nitrogen concentration (Páez et al., 2001).

Pollution

Many reservoirs receive tributaries with pollutants, which are not quantified and, therefore, represent risks for human health Ortaz et al. (1999) observed residual water from a galvanic factory runs freely through the La Pereza reservoir basin. This residual water has not been studied yet.

Adjacent areas of Guanapito reservoir (which supply drinking water to 44,000 inhabitants from Altagracia de Orituco population), are used for extensive livestock, fruit culture and horticulture, which directly supply fertilizers and biocides to the water body through runoff and through its tributaries (Infante et al., 1992; González et al., 2009a). Biocide concentrations need to be quantified.

Heavy metals have been found in sediments from many reservoirs. Álvarez et al. (2007) registered concentrations of Co, Cr, Cu, Ni and Zn higher than the values considered as base in Quebrada Seca, Lagartijo and La Pereza reservoirs. The presence of this contamination in sediments could be related to the water pumped to these reservoirs by the Tuy River, which receives high industrial and waste water discharges (González et al., 2009a).

Lowered water flow and high water demand: The growing water demand from some cities could have a negative effect on the water level of some reservoirs. This is the situation of Agua Fría, an oligotrophic reservoir located in a National Park, which provides drinking water to

Los Teques City (ca. 172,000 inhabitants). This could affect its water quality, because submersed aquatic vegetation could be exposed out of the water, allowing its decomposition and the following nutrient release to the reservoir (González, 2002; González et al., 2009a).

Another example can be drawn in the Camatagua reservoir, which actually is the biggest water reserve for Caracas City. In recent years, it suffered a significant volume diminution, affecting water supply to Caracas. This change could be attributed to the human activities in the basin (mainly deforestation), and probably, due to the change in the rainy pattern in this region. Water level remained, from 2001 to 2004, more than 20 m below its normal operation level, generating a rationing program in the drinking water supply for Caracas City (González et al., 2009a).

6. Legal Instruments and some Regulatory Standards for Water Management in Venezuela

In Venezuela, there are lots of regulatory standards and laws concerning the water conservation and water resources management, which constitute examples of good practices related to water resource management.

The principal of them is the National Constitution of Bolivarian Republic of Venezuela, promulgated in 1999.

Elsewhere the traditional resolutions about the country sovereignty over its aquatic spaces (lacustrine and fluvial freshwaters, territorial sea and interior seawaters), National Constitution established articles related with environmental aspects of water resources and water quality (MINAMB, 2006), and claims that water is public domain, as the Civil Code does too. Other group of important laws is listed below (according to MINAMB, 2006):

- Forestry Law of Soils and Waters (1966): Declares public utility of hydrographic basins, watercourses and waterfalls protection.
- Organic Law of Environment (1976): It refers, holistically, to environmental protection, included water components and water bodies.
- Penal Law of Environment (1992): Establishes sanctions for those actions and activities that damage the environment.
- Law-Decree of Coastal Zones (2001): Regulates administration, use and management of these zones, in order to obtain their conservation and sustainable utilization, including protection of biological diversity, control of environmental deteriorating activities and control of pollutants from terrestrial and aquatic sources, wastewater treatment, economical valuation of natural resources, among other resolutions.
- Law for Dangerous Substances, Materials and Residues (2001): Forbids aerial application of biocides on water bodies destined for human consumption, watering and livestock.
- Law of Lands and Agrarian Development (2001): Favors rational utilization of waters that could be used for irrigation and aquiculture.
- Organic Law for Potable Water Lending and Sanitation (2001): Attributes competition to the Municipalities for control and lending of water services.

- Organic Law of Aquatic and Insular Spaces (2002): Promotes international cooperation concerning with transbourdary hydrographic basins and water courses.
- Law of Fishing and Aquiculture (2003): Consecrates the precaution principle of the aquatic environment.
- Organic Law for Planning and Management of Territory Ordination (2005-2006): Established resolutions to guide the planning and management of territory ordination, according to ecological principles.
- Law of Waters (actually is discussed in the National Assembly): It will establish resolutions about water uses.

Other sub-legal regulations, concerning with juridical protection of water and water bodies, are:

- Standards for Regulation and Control of Water and Hydrographical Basins Utilization.
- Standards for Classification and Control of Water Bodies and Liquid Effluents Quality (Decree 883, 1995).

Standards about Evaluation of Environmental Deteriorating Activities.

Standards for Regulation of Activities that Promote Flow Change, Channel Obstruction and Sedimentation Problems (1992).

- Decree that rules Reservoir and Adjacent Area Uses (1991).

Venezuelan State has a relevant concern about water resources, although some bad practices can be observed in some regions of the country. Other examples of good and bad practices related with water management in Venezuela will be illustrated in the following sections.

7. Institutions Related with Water Management and Research

There are many Institutions related with water management and research in Venezuela. MINAMB (2006) shows a list of some institutions related with National Public Administration:

- Ministry of Environment. This Ministry is the National Authority on Water.
- Ministry of Foreign Affairs.
- Ministry of Planning and Development.
- Ministry of Agriculture and Lands.
- Ministry of Health.
- Ministry of Education, Culture and Sports.
- Ministry of Science and Technology.
- Public State and Municipality Administration. It concerns Governors and Majors.
- Public Decentralized Administration and Governmental Enterprises. Such as PDVSA, Regional Corporations of Development, Autonomous Institutions.
- National Universities and Centers of Research. They include one Institute of Limnology and some Laboratories of Limnology.
- Hydrological companies, private companies that depend or are ascribed to Ministry of Environment, deal with drinking water supply and sanity.

8. Examples of Practices related with the Water Management and Quality in Venezuela

There are some examples related with the practices dealing with water management and quality in Venezuela. Venezuelan State, as previously mentioned, has a relevant concern about water resources, and issued many regulatory standards in order to assure the protection of natural (water) resources and the good water quality that is supplied for diverse purposes. Elsewhere, Ministry of the Environment has invested high amounts of money to recover the water quality in some reservoirs, and has invested a lot of time to organize communities in order to capacitate them for solving their problems and protect their natural resources. Some examples will be depicted in the following paragraphs.

8.1. La Mariposa Reservoir Case:

Reservoir suffers high and frequent level fluctuations due to the high water demand of the city of Caracas, and water pumping from Camatagua and Lagartijo reservoirs. Its basin is highly impacted and eroded, which directly contribute with a lot of nutrients and sediments to the water body.

In October 2005, the water hyacinth Eichhornia crassipes began to cover the reservoir surface, affecting even more its water quality.

From January to May 2007, irregular macrophyte removal was made, and due to this fact, without success; macrophyte covered up to 85% of reservoir surface. In May 2007, Ministry of the Environment ordered the removal of the macrophyte. The population of E. crassipes was almost entirely removed in few days, using mechanical harvesting. However, water quality was affected, as it can be seen in Table 2, because of the high amounts of organic matter from dead plants that were accumulated in the reservoir bed.

Removal of water hyacinth was the right action, but this macrophyte increased their high population densities again at the end of 2008, because of the lack of a systemic and periodical removal of plants. Plants covered more than 50% of water surface by February 2009, and a new removal plan is been applied today. Eutrophication sources are still present around the reservoir, and therefore, if not controlled, E. crassipes will increase in numbers once again.

Table 2. Water Quality in La Mariposa Reservoir before, during and after the Presence of Eichhornia Crassipes.

	Jan. 2001	Jan. 2007	Jan. 2008
Transparency (m)	0.7	1.3	0.3
Temperature (°C)	24.9	24.6	25.2
Dissolved oxygen (mg/l)	7.0	3.8	2.7
Conductivity (µS/cm)	302	347	416
pH	8.05	7.60	8.13
Total P (µg/l)	123	153	308
Total N (µg/l)	1383	844	2261
Condition	Without E. crassipes	Covered with E. crassipes	E. crassipes removed

8.2. Pao-Cachinche Reservoir Case:

Reservoir tributaries transport untreated waste water from Valencia City, and waste water from poultry and pig farms. Thus, tributaries introduce high level of nutrients into the reservoir (González et al., 2004a; 2004b). Cyanobacteria blooms were common during the rainy season period. Therefore, reservoir is highly eutrophic.

After limnological characterization, which was carried out by Laboratory of Limnology of Central University of Venezuela, remedial measure was suggested to the hydrological companies. Thus, in November 2001 the process of artificial destratification of the reservoir started, which effectively controlled the eutrophication effects after one year of continuous operation, representing the first and successful case of water quality enhancement in Venezuela (Estaba et al., 2006). Results of artificial destratification can be enumerated as follows:

- Increase of water transparency
- Gradual loss of thermal stratification
- Decrease of epilimnetic dissolved oxygen concentrations as compared with the previous supersaturated values
- Hypolimnetic oxygenation (deep layer of cold temperature)
- Decrease of surface values of pH
- Decrease of ammonia, N-Kjeldahl y total P concentrations
- Homogenization of physical and chemical conditions
- Decrease of relative proportions of cyanobacterias
- Loss of cyanobacterial blooms.
- Increase of relative proportions of green algae.

This case represented a good example of interaction between scientists and planners, hydrological companies and universities, which achieved the water quality enhancement that is supplied to population for drinking purposes.

However, Pao-Cachinche reservoir was after affected due to the rise of water level of Lake Valencia. At the end of 70´s, Lake Valencia was suffering a natural desiccation process, which was accelerated by human activities, and reached to its lowest level (402 m.a.s.l.). Since then, water levels have risen due to diversion of water from neighboring watersheds, mainly the Cabriales stream. As a consequence of this diversion, Lake Valencia waters flooded agricultural and urban areas, although urban settlements around the lake were forbidden. Due to these facts, together with population and media pressures, from November 2005 the Maruria and Cabriales streams were deviated to the Pao stream basin, through the Paito stream, one of the main Pao-Cachinche tributary.

The high organic load contained in these streams had again caused the oxygen depletion in the water column of the reservoir, and all the benefits obtained after the artificial destratification were reverted. Actually, water from Lake Valencia is directly pumped through Paito stream.

In order to mitigate this situation, an effective waste water treatment before discharging streams to the Pao-Cachinche tributaries must be made. A nutrient reduction program must be imposed, with a real protection of the reservoir basin.

8.3. Regulatory Standards:

One of the main regulatory standards is represented by the Decree 883, promulgated in 1995. Among other regulations, established maximal limits allowed for phosphorus and nitrogen concentrations in the waste waters: 10,000 μg/l for total phosphorus, 40,000 μg/l for total nitrogen and 10,000 μg/l for nitrates + nitrites. These limits are high in extreme and therefore, do not contribute to enhance or protect the water quality of the reservoirs. Actually, this decree must be submitted to revision.

8.4. Technical Roundtables for Water Problems:

The Venezuelan Government encourages communities to get involved in improving their quality of life. Technical Roundtables for Water Problems (TRWP) emerged as an alternative for solving problems related to drinking water and environmental sanitation in Venezuela, in a participatory way. Venezuelan government is also creating structures called Community Water Councils, where all the TRWP converge to present their problems and offer their ideas (Salazar, 2009).

From 1999, communal organizations have been conformed in urban and rural areas, which have been called Technical Roundtables for Water Problems (TRWP), with the aim of enhancing the maintenance of drinking water supply and sanity services. These TRWP have been become a fundamental mechanism for the community organization, and helping in the development of a new culture for water conservation.

Technical Roundtables for Water Problems (TRWP) are good examples of community participation. Based in the National Constitution of the Bolivarian Republic of Venezuela, the hydrological company HIDROVEN and its filial enterprises, promote the conformation of these TRWP (Arconada, 2005, 2006).

National Constitution of Venezuela, Organic Law of Lending of Drinking Water Services and Sanity (LOPSAPS), establish the legal framework and mechanisms for transferring water services management from the hydrological companies to Municipalities.

Hydrological companies, together with TRWP, are co-responsible in the diagnosis of problems, making and execution of projects, and doing comptroller functions.

Venezuelan Government created the Fund for Finances Community Projects, in order to support these TRWP, which have become in a pioneer experience in the direct economical fund management for the execution of projects related with water supply and sanity. Communities have been designed these projects on their own. Then, the functioning of TRWP is as follows: Communities meet, they present their problems and devise their projects, and when the financing comes through, they carry out the work.

Actually, more than 6500 TRWP are operating in Venezuela. Some of their achievements are:

- More than 1,200,000 of inhabitants have been benefited.
- More than 1000 projects have been executed, with an investment of more than US$ 100,000,000.
- Inclusion of more than 600,000 inhabitants to the national water system.

This strategy of participation has decisively contributed to the main objective of extending the population access to drinking water supply and sanity. Moreover, communities have progressively widened the range of their interests: initially concerned with the immediate problems of access to drinking water and its quality, they have moved on to consider broader problems, including the environmental problems of the river basins.
In conclusion, there are a growing number of Venezuelan communities that deal with their

own problems related with water supply and sanity, increasing the national coverage for these services (Table 3).

Table 3. National Coverage of Drinking Water and Sanity Services in Venezuela (1998-2003). Modified from Arconada (2005).

Year	Drinking water supply (% of population)	Residual waters collection (% of population)
1998	81.57	63.77
1999	83.66	64.38
2000	85.15	66.96
2001	86.37	68.15
2002	87.65	71.27
2003	89.27	71.69

9. Conclusions

Venezuela has abundant water resources and valuable experiences in their management. However, numerous problems still persist and they have to deal with. National Academies of Sciences, through the Water Program of IANAS, could help by: promoting better relations between scientists and decision-makers, promoting specialization courses at national and regional levels, promoting and strengthening the scientific capacity among the countries, promoting joint projects, elaborating guidelines to promote the integrated management of water resources, promoting the linkages of governmental agencies and professional associations dealing with the management of water resources, promoting the articulation between scientific groups at regional levels, promoting studies to assess the environmental value of water service in terms of environmental goods and services, raising awareness on long term systematic monitoring, raising awareness to bring high attention into political agenda to prioritize wastewater treatment and disposal. All of these actions will strengthen national capacities for an adequate water resources management.

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11. References

1. Álvarez, M. A., F. Méndez & J. Chirinos. 2007. Estudio ambiental preliminar de los sedimentos de tres embalses de la región centro norte de Venezuela. Ciencia, 15: 259-269.
2. Arconada, S. 2005. La experiencia venezolana en la lucha por un servicio de agua potable y saneamiento encaminado a cubrir las necesidades de la población. In: B. Balanyá, B. Brennan, O. Hoedeman, S. Kishimoto & P. Terhorst. Por un modelo público de agua. Triunfos, luchas y sueños. Transnational Institute, Corporate Europe Observatory & El viejo topo, Amsterdam: 141-146.
3. Arconada, S. 2006. Mesas Técnicas de Agua y Consejos Comunitarios de Agua. Revista Venezolana de Economía y Ciencias Sociales, 12: 127-132.
4. Cabrera, A. L & A. Willink. 1980. Biogeografía de América Latina. Secretaría General de la Organización de

los Estados Americanos. Programa de Desarrollo Científico y Tecnológico. Serie de Biología N° 13. Washington, D.C., 122 pp.
5. Cañizales, A., S. Peñuela, D. Díaz Martín, M. E. Febres, O. Caldera, L. Valderrama & E. Mujica. 2006. Gestión integrada de los recursos hídricos en Venezuela. Informe del Proyecto de Gestión Integrada de Hídricos. Vitales. Caracas, 60 pp.
6. Estaba, M. de, E. J. González & M. L. Matos, 2006. Desestratificación artificial en el embalse Pao-Cachinche: Primer y exitoso caso de mejoramiento de la calidad del agua en 17 Venezuela. In: J.G. Tundisi, T. Matsumura-Tundisi & C. Sidagis-Galli (Eds.). Eutrofização na América do Sul: Causas, conseqüências e tecnologias de gestão. Rede EUTROSUL, PROSUL, Instituto Internacional de Ecologia. São Carlos, Brazil: 439-456.
7. Gaceta Oficial, 1995. Normas para la clasificación y el control de la calidad de los cuerpos de agua y vertidos o efluentes líquidos. Decreto 883. República de Venezuela. Caracas.
8. Gobierno en Línea, 2009. Venezuela. In: www.gobiernoenlinea.ve/venezuela (consulted: February 17th, 2009).
9. González, E. J. 2000. Nutrient enrichment and zooplankton effects on the phytoplankton community in microcosms from El Andino reservoir (Venezuela). Hydrobiologia, 434(1): 81-96.
10. González, E. J. 2002. Caracterización limnológica de los embalses Agua Fría (Estado Miranda) y Tierra Blanca (Estado Guárico). Proyecto S1 – 98001361. Etapa I: Caracterización limnológica del embalse Agua Fría (Parque Nacional Macarao, Estado Miranda). Informe técnico presentado al FONACIT. Caracas.
11. González, E. J. 2008. Eutrofización de embalses en Venezuela. Memorias del Instituto de Biología Experimental, 5: 169-172.
12. González, E. J. & M. Ortaz. 1998. Efectos del enriquecimiento con N y P sobre la comunidad del fitoplancton en microcosmos de un embalse tropical (La Mariposa, Venezuela). Revista de Biología Tropical 46: 27-34.
13. González, E. J., M. Ortaz, C. Peñaherrera & M. L. Matos. 2002. Eutrofización y manejo de embalses en Venezuela. Caso del embalse Pao-Cachinche. In: A. Fernández-Cirelli y G. Chalar-Marquisá (Eds.). El agua en Iberoamérica. De la Limnología a la Gestión en Sudamérica. Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo, CYTED XVII. Aprovechamiento y Gestión de Recursos Hídricos; Centro de Estudios Transdisciplinarios del Agua; Facultad de Ciencias Veterinarias de la Universidad de Buenos Aires. Buenos Aires: 81-90.
14. González, E. J., M. Ortaz, C. Peñaherrera, E. Montes, M. L. Matos & J. Mendoza. 2003. Fitoplancton de cinco embalses de Venezuela con diferentes estados tróficos. Limnetica, 22: 15-35.
15. González, E. J., M. Ortaz, C. Peñaherrera & A. Infante. 2004. Physical and chemical features of a tropical hypertrophic reservoir permanently stratified. Hydrobiologia, 522: 301-310.

16. González, E. J., M. Ortaz, C. Peñaherrera & M. L. Matos. 2004. Fitoplancton de un embalse tropical hipereutrófico (Pao-Cachinche, Venezuela): Abundancia, biomasa y producción primaria. Interciencia, 29: 548-555.
17. González; E. J., M. L. Matos & M. Ortaz. 2009a. Management and general problems of tenreservoirs in North – Central Venezuela. Interacademy Panel Water Programme Regional Workshop for the Americas.
18. González, E. J., M. A. Álvarez, M. Barrero & H. Finol. 2009b. Limnología y efecto de los impactos antrópicos sobre los peces de interés comercial del embalse de Suata (Estado Aragua) y del Lago de Valencia (Estados Aragua y Carabobo). Informe final de la Etapa I del Proyecto de Grupo PG 03.00.6495.2006. Informe técnico presentado al CDCH-UCV. Caracas.
19. Infante, A., O. Infante, T. Vegas & W. Riehl, 1992. Proyecto multinacional de medio ambiente y de los recursos naturales. Informe I etapa (embalses Camatagua, Guanapito y Lagartijo, Venezuela, y Las Canoas, Nicaragua). Universidad Central de Venezuela y Organización de los Estados Americanos. Caracas.
20. Infante, A., O. Infante & E. J. González, 1995. Proyecto Multinacional de Medio Ambiente y de los Recursos Naturales. Informe final: II etapa (embalses El Andino y El Cují). Universidad Central de Venezuela y Organización de los Estados Americanos. Caracas.
21. MINAMB. 2006. Recursos hídricos de Venezuela. Ministerio del Ambiente y Fundambiente. Caracas, 167 pp.
22. MINAMB. 2007. Rehabilitación de presas a nivel nacional. Organización para la rehabilitación y mantenimiento de embalses. Ministerio del Poder Popular para el Ambiente (MINAMB). Serie de Informes Técnicos, DGEA/IT/864. No. X-002/P-129/02 Rev. B. Caracas.
23. Ortaz, M., E. J. González, J. Manduca, C. Peñaherrera & E. Montes, 1999. Características limnológicas de los embalses La Pereza, Lagartijo, La Mariposa y Quebrada Seca y preservación del zooplancton como controlador de microalgas, mediante técnicas de biomanipulación. Informe técnico presentado a las compañías Hidroimpacto C.A. e Hidrocapital. Universidad Central de Venezuela. Caracas.
24. Páez, R., G. Ruiz, R. Márquez, L. M. Soto, M. Montiel & C. López. 2001. Limnological studies on a shallow reservoir in western Venezuela (Tulé reservoir). Limnologica 31: 139-145.
25. Rodríguez-Betancourt, R. & J. González-Aguirre. 2000. El manejo de los recursos hídricos en Venezuela. Instituto Internacional del Manejo del Agua. IWMI, Serie Latinoamericana N° 18. México, D.F., 42 pp.
26. Salazar, M. C. 2009. Collective Solutions to Water and Sanitation Problems. In: B. Bell, J. Conant, M. Olivera, C. Pinkstaff & P. Terhorst (Eds.). Changing the Flow: Water Movements in Latin America. Food and Water Watch, Other Worlds, Reclaiming Public Water, Red VIDA & Transnational Institute, Amsterdam: 36-37.

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IANAS WATER PROGRAM

Encouraging awareness and knowledge in society in which concerns the worth of water and its status in our planet is a fundamental task of our times. Like in many places around the world, American countries face water problems that demand a better management in order to fulfill people's demands.

Such problems include: scarcity and pollution of water, the need for better water management, the lack of ecological order, the impact of climate change on the water cycle and the low investment in research and technological development in countries.

Hence the idea of writing this book which consists of 15 chapters, most of them written by several authors who take care of the particularities and needs of their countries. This work brings together the opinions and knowledge of 66 specialists in the field of water coming from Argentina, Bolivia, Brazil, Canada, Chile, Colombia, Costa Rica, Cuba, United States, Guatemala, Mexico, Nicaragua, Peru, Dominican Republic and Venezuela which comprise the Water Program of IANAS.

It will be seen, that challenges regarding water in the continent are remarkable: scarcity, pollution and climate change impact. Facing these issues requires a strengthened management where all the users work together.

Blanca Jiménez-Cisneros and José Galizia-Tundisi
Co-Chairs
IANAS Water Program

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