Carlos Eduardo de Mattos Bicudo ·
José Galizia Tundisi ·
Marcos Cortesão Barnsley Scheuenstuhl
Editors

Waters of Brazil

Strategic Analysis

Instituto de Botânica

INSTITUTO INTERNACIONAL DE ECOLOGIA
International Institute of Ecology

ACADEMIA BRASILEIRA DE CIÊNCIAS

Springer

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*We dedicate this book to all students
and scholars of water in our country.
We hope you all grant the worth water
deserves as well as the prominent position
within our country research.*

Preface

The water crisis of the twenty-first century is not only a crisis of scarcity and water stress, but above all, a crisis in management. New and creative water management and governance possibilities can, on the other hand, be developed based on an interaction among researchers and managers by means of supporting management projects and training courses. Moreover, permanent strategic analysis and technological forecasting are increasingly necessary to reduce the vulnerability and the risks of shortages, deterioration of water quality and of scarcity.

Based on this assumption and understanding that this is indeed a challenge that requires action, the Brazilian Academy of Science (ABC) put together a Water Resources Study Group, in March 2008, and gave them the task of gathering renowned Brazilian researchers who work with the water issue, to establish the Academy's vision on strategies for optimizing uses of water resources in our country. In May 2008, at ABC's Magna Meeting, the study group held its first meeting, together with the symposium "Water Resources in Brazil: Strategic Challenges." These two events were crucial for the launching of the core study areas of the Study Group coordinated by the Academic José Galizia Tundisi.

In August 2008, the Group, in partnership with the Inter-American Network of Academies of Sciences (IANAS) and with the Inter-Academy Panel on International Issues (IAP), promoted a Regional Seminar and a Training Course for the Americas, focused on "Water, environment and society: an integrated approach." In addition to several Brazilian water resources researchers and managers, this event, which was held in the city of São Carlos, counted with the participation of researchers and managers of 13 countries of Latin America and of the Caribbean region, all of them highly qualified professionals linked to the national water systems of their respective countries.

In September 2008, the Group held a business meeting where they decided upon the production of a White Paper on Waters in Brazil, presenting a strategic vision on the use of water resources in the country. For the making of a first version of this paper, work groups were created with the challenge of elaborating articles on crucial strategic issues. The groups worked intensely throughout the year of 2009 and presented the results of their initial efforts at the symposium "The Water Crises and National Development: A Multidisciplinary Challenge." The meeting was held in

Belo Horizonte, in October 2009, in a partnership between ABC, the Federal University of Minas Gerais (UFMG), and Research Support Foundation of Minas Gerais (FAPEMIG).

This publication brings to the public a summary of the discussions held in Belo Horizonte, representing the first product of the ABC's Study Group on Water Resources. New analysis and assessments will be developed in the following months, aimed at consolidating the White Paper on Waters in Brazil. Through these efforts, ABC tries to contribute to the Brazilian society in this crucial issue for the improvement of the quality of life of our people.

It is important to highlight that this work is developed based on an innovative point of view, which aims at overcoming a dichotomy that exists today between ground water and surface water. Based on an integrated and holistic point of view, the water cycle is seen in its entirety, and it is understood that there is one common source of problems (pollution, overexploitation, excessive use) that result in different processes (eutrophication, contamination) and symptoms (toxicity, salination). The Group's work attempted to link technological and ecological solutions integrating quantitative and qualitative aspects of the water resource. Such a perspective allows for a sustainable management of the water resources based on conceptual connections that foster an articulated work among the different fields of science, which then supply a systemic approach that enables managers the possibility of an integrated action focused on anticipating problems and solutions.

With this initiative, ABC seeks to encourage the work of researchers and managers of water resources, promoting a greater integration between these two communities. Such interaction will facilitate the exchange of information to those who need this knowledge to develop a management process that is rational and structured on scientific information. Furthermore, the strengthening of the dialogue among these two agents will enable that managers present to scientists the main problems and constraints of management, thus promoting the development of new researches and innovations that aim at meeting the pressing needs in the field of water resource management.

Finally, it is worth noting that this initiative of ABC falls within the scope of the Millennium Goals of the United Nations (UN), which has as one of its components to improve water availability, in a long term and sustainable way, to the millions of men and women who today do not have satisfactory access to this crucial asset for human existence.

We cannot miss highlighting the fundamental support of the Ministry of Science and Technology (MCT) and its agencies the National Council of Scientific and Technological Development (CNPq) and the Financier of Studies and Projects (FINEP), in promoting the works of ABC's study groups, among which is the Study Group on Water Resources. We would also like to thank the support of the Botanical Institute of the Environmental Department of the State of São Paulo, without whose support the publication of this book would not have been possible.

Jacob Palis
President of the Brazilian Academy of Sciences

Knowledge

Brazil is a privileged country with regard to its natural resources, among which are the surface and ground water resources which have a relevant ecological, economical, strategic, and social role. With approximately 14 % of the Planet Earth's fresh water, Brazil however has serious problems with regard to diagnosis, strategic assessment, and management of its water resources.

Although ANA's latest survey report, of 2009, indicates real progress in the management and diagnosis of the situation of surface and ground water (quantity and quality), there is still the need for further advances in the strategic analysis of water resources with an economic input, with repercussion to the social aspect and to the development of Brazil.

This was the purpose of establishing a scientific commission in the Brazilian Academy of Sciences focused on water resources, with the objective of organizing seminars and strategic and critical positioning analysis together with critical assessments. This commission of specialists has, therefore, a fundamental mission, which is that of including the Brazilian Academy of Sciences in an important process of contribution towards the deepening of scientific knowledge, towards promoting new ideas and new mechanisms for the management of water resources, and to offer, to the Brazilian society, to the federal, state and municipal governments, a consistent set of information that will be able to guide the public policies related to this issue and which can be added to new initiatives. This activity of the Brazilian Academy of Sciences is linked to two important international programs: IANAS (Inter-American Network of Academies of Science) water program and IAP (Inter-Academy Panel) water program. IANAS program has the objective of supporting the Science Academies of different countries of the Americas to establish commissions on water resources with the objective of preparing studies to promote a strategic approach to the national water resources and present new perspectives and innovative solutions for the management of the water resources. The IAP program has the objective of supporting a worldwide network of training of water resource managers, who have an integrated and systemic view of the process.

The current publication is one of the results of ABC's efforts. Contributions from specialists in climate changes, management of water resources, water and human health, water quality, ground water, water reuse, water and economy, aside from analysis on innovation, on semi-arid and Amazonia, hereby present an amazing set of assessments of information and of high quality ideas that perfectly fulfill the assignments of the Water Resources Commission of the Brazilian Academy of Sciences.

The specialists performed a job that is without doubt a valuable contribution aimed at the future. To all the authors, our sincere thank you, and congratulations for your commitment to the future of Brazil.

São Carlos, SP, Brazil José Galizia Tundisi

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Chapter 1
Management of Water Resources and Irrigated Agriculture in Brazil

Marcos V. Folegatti, Rodrigo M. Sánchez-Román, Rubens D. Coelho, and José A. Frizzone

Abstract Water resources management in Brazil had a substantial quality improvement during the last 30 years. During that period, a multi-objective public administration point of view was established, which had led to: (a) environmental, social and economic sustainability; (b) compatibility among public institutions and public laws; and (c) new set of policies to promote people's participation. Water resources management law (9,433/1997) and the creation of the National Water Agency (Agência Nacional de Águas) are benchmarks of this period. A share water resources management organization is a social challenge due to the fact that public financial resources becomes diluted as population grows, environmental problems increase and the world's economic crises amplify its consequences. Brazil being a commodities producer could benefit from the world economic crises and the global warming tendency, considering its geographic extension and location. Facing this dilemma, how the Brazilian society will confront new water resources demands in the near future? This is the challenge set to public policies decision takers.

Keywords Agriculture • Governability • Irrigation • Policies • Shortage • Water resources

Situation of Water Resources in Latin America and in Brazil

Latin America and the Caribbean compose about 8.4 % of the world's population. The average annual runoff from natural precipitation in the region is of 13,120 km^3, representing 30.8 % of the planet's volume. Rainfall is around 1500 mm year^{-1}, being 50 % superior to the world's average; but two thirds of the runoff volume concentrates into three basins (Orinoco, Amazonas and Rio da Prata). In addition,

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25 % of the areas of the region are arid or semiarid, as a result of uneven distribution of rainfall.

The main users of water resources in the region are: agricultural immigration, the supply of drinking water (urban and rural) and sanitation, including the transportation and dilution of sewage by water, and hydropower generation. The average efficiency of irrigation in the region is of 45 % (IDB 1998—Brazilian Disclosure Index).

In the last century, the total demand of water increased by six times, while the population only increased by three (Tutti 2009). The accelerated demand over the water resources creates, initially, a problem of quantitative scarcity of the resource, while simultaneously it reduces the quality of the water due to the increase in population. This increase produces a growth in industrialization, in the use of pesticides in agriculture and in the inadequate use of the soil and of the water. The waters that were polluted due to anthropogenic activities return to the bodies of waters[1] from where they were taken, with considerable inferior quality.

In the whole world and in Brazil, agriculture is the main consumer of water. It is estimated that 69 % of the water consumed in the world is for agriculture, 23 % is dedicated towards industry, and 8 % goes to supply the population. In Brazil, these percentages are, respectively, 68 %, 14 % and 18 % (Tutti 2009). Still with regards to Brazil, 54 % of all houses have effective systems of sewage collection (MMA/ANA 2007—Ministry of Environment/National Water Agency), yet, only 20 % of urban sewage undergoes some sort of treatment (Kelman 2007).

Over time, the demand generated by water has decrease the availability per capita and decreased its quality, thus generating conflicts about the water usage, since water of inferior quality cannot be easily used for consumption, for production or for leisure.

It was estimated that South America would present an increase in the demand for water of 70 % between 1990 and 2025, while the consumption by agriculture would vary from 81 to 69 % during the same period. The greatest percentage increases correspond to the industries and to the evaporation of water from the reservoirs, however agriculture will continue to be the main consumer of water, followed by the evaporation of water from reservoirs, by population supply and lastly, by the industry (IDB 1998).

The Brazilian energy matrix is dependent on water availability since around 90 % of production comes from hydropower. If the observed trend of climatic changes confirms itself in the next years, Brazil may find itself being benefited or harmed as a result of future variations which may occur in its national territory, due to having its matrix so strongly dependent on hydrologic factors. Therefore, the energy matrix should undergo alterations with the support of other sources and usage strategies of the water resources (Tucci 2009).

In a research performed in 2004 by IBOPE, 88 % of Brazilians believed that the country would face problems related to water supply sooner or later, of which 74 %

[1] It has been estimated that on average, for every unit volume of water used (for domestic and industrial purposes) that is returned to its receiving bodies, the contamination affects about 8–10 equivalent volume of natural water (WMO/IDB 1996).

of those interviewed indicated that they would support bills that stipulated the payment for the volume of water consumed, with the objective of creating programs to bring awareness to the people about ways to use water efficiently and about and recovery and protection of basins. Yet, 70 % of those interviewed, said that they had never heard about the watershed committees; of those who had, 92 % of them do not know anyone who actually participates in a watershed committee. This research indicated that those interviewed are actually aware of the future problems which can derive from the scarcity of water, yet the management mechanisms which represent the watershed committees have not permeated the Brazilian society as was expected.

Irrigated Agriculture in Brazil

On several debates in Brazil and around the world, on management of water resources of the planet, there has been a consensus that irrigation is an effective instrument which aids in the production of food, but that due to the growing population of the world, will face an even greater demand. Yet, how much water should be allocated to the production of food and how much of it should be kept for the functioning of the ecosystems?

This is a discussion of extreme importance. It is known that irrigated agriculture is what diverts the most water from the environment towards the production of food. Currently, irrigation is practiced in 17 % of all the arable areas of the planet, producing 40 % of the world's food and utilizing approximately 70 % of all the waters which is removed from water bodies in the planet. It is estimated that in order to meet the demands for food, the irrigated area will increase by 20–30 % by 2025 (Nunes 2009). Although Brazil is the holder of approximately 12 % of the planet's freshwater, most of it (70 %) is found in the Amazon Basin. The remaining 30 % of the available volume of freshwater has to supply 93 % of Brazil's population, as well as irrigated agriculture. This economic activity consumes almost half of the water in about 5 % of the irrigated area; yet, the urban and rural consumption by humans corresponds to 27 % of 'total water use' (MMA/ANA 2007).

With this in mind, the Ministry of Environment and the National Water Agency (MMA/ANA 2007) have indicated that by 2020, there will be a need for structural changes in three of the main users of Waters in the country: agriculture, power generation and dilution of domestic and industrial sewage. But other changes will also be necessary since the resources are distributed unequally geographically and in terms of population, and require a national vision of distribution of the human and economic resources to ensure an environmental sustainability of these ecosystems where economic centers exist.

Three of the eight countries with the greatest biocapacity in the world (Unites States, China and India) are ecological debtors. Their ecological demands exceed their own capacity. Of the other eight, Brazil has 5.3 ha of available biocapacity per capita and 3.5 ha per person of ecological demand, with a positive balance of 2.3 ha

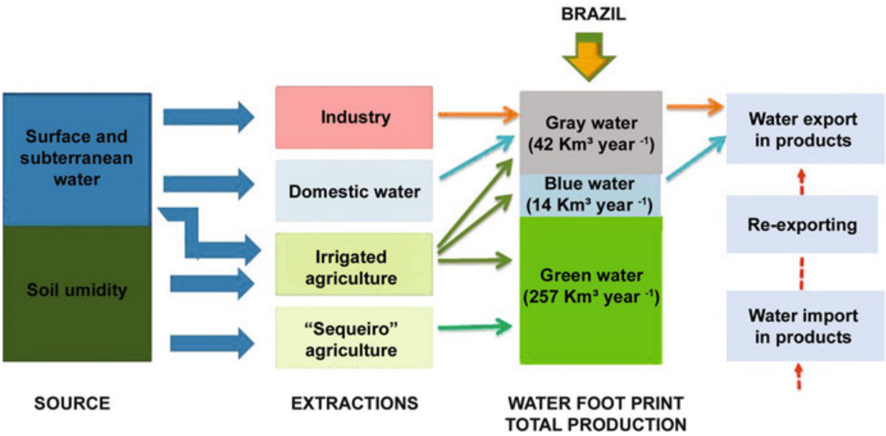

Fig. 1.1 Components of the water demand, emphasizing the values of Brazil (elaborated by the authors based on data from WWF 2008)

(WWF 2008). With regards to water demand,[2] Brazil uses 1400 m^3 of water per person per year; of these 1250 m^3 per person per year are from products which originated from the country, and 150 m^3 per person per year are from imported products. The global average water demand is of 1240 m^3 per person per year.

The components of the water demand in Brazil are shown in Fig. 1.1, with the values reported by WWF (2008).

Brazil currently irrigates 3.4 million hectares (Christofidis 2006), of which 2.2 million hectares of the total amount are irrigated by pressurized systems. According to ANA (2004), the equivalent flow (continuous for 24 h) currently consumed in the irrigated areas of Brazil is of approximately 589 m^3 s^{-1}. The country has an irrigation potential whose estimate vary between 22 and 30 million hectares. Although the irrigated area in Brazil is not proportionally large, it has been noted that in specific cultivations, its use is intensive, especially in commercial areas. In the last 25 years, productivity has doubled, in part due to the use of irrigation. The inefficient irrigation has generated salination and draining problems in 15,000 ha, mainly in the northeast of the country (AQUASTAT 2000). The irrigated area in Brazil is responsible for more than 16 % of the total volume of production and 35 % of the

[2]The water demand of a country is the total volume of water used globally to produce the goods and services consumed by its inhabitants. Sometimes it is referred to as the virtual water content of a product. The exports of a country are not included in the estimated demand of water. As examples of water demand, one can indicate that the following is needed: (a) 2900 L of water to produce one shirt made of cotton, when 3.7 % of the global use of water in agricultural production is used to cultivate cotton. This equals 120 L per person per day; (b) 15,500 L for every kilo of beef produced, when 23 % of the water used in agriculture is used for the production of livestock products. This equals 1150 L per person per day; (c) 1500 L of water per kilo of sugarcane produced, being equivalent to 3.4 % of the water used in agriculture. This equals 100 L per person per day when 70 g of sugar is consumed (WWF 2008).

total economic value of production, while in the world these numbers are of about 44 % and 54 % respectively.

Within the next 10 years, there is the prospect of increasing the total area of sugar cane plantation to 12 million ha. in Brazil. The expansion of the cultivation to new areas may boost the implementation of irrigation in a larger scale for this type of cultivation.

The other crops with great plantation areas (soybeans, cotton, wheat, cassava and corn) have a low perspective of large-scale irrigation (Coelho 2007), since Brazil is very competitive in the foreign market, based on an agriculture that utilizes rain water to ensure the needed soil humidity for the development of the crops.[3]

For several people, irrigation is considered to be very costly and therefore, questionable financially and economically because of the low prices of products in the international markets. A revision of the experiences of the World Bank (Jones 1995) showed that irrigation projects produced, over all, positive economic return rates on average 15 % greater than the opportunity cost of capital and greater than the averages of other agricultural projects without irrigation.

Some critics rely on the mistakes made in the last century in the 1970s, when the increase of the water supply and the development of the infrastructure were done without any technical support and without the evaluation on how to improve the performance of the project, which is essential for the success of irrigation. Since that time, lessons have been learned and conditions have changed and it's time to go forward. If correctly applied, with well-defined goals for technical assistance, irrigated agriculture can help solve several problems such as: water scarcity, poverty and production of food, promoting and optimizing regional development, generating jobs, ensuring food security, increasing and diversifying production, decreasing the risks of agriculture and improving quality of life. Yet, for this to occur, it is essential there be a planning of land and water use from the different sub-basins where irrigation is possible.

According to Hall (1999) some of the most important policies which were created as a result of the lessons learned from the past and from international forums are: (a) water saving: there is broad acceptance of market mechanisms and the concept of water as an economic good; (b) integrated management of water resources: the need to holistically manage water become a familiar message among those who work with water resources; and (c) institutional reform: the focus on institutional issues have major implications on irrigation.

The development of irrigated agriculture is therefore a priority, and requires a solid base in order for actions to be established at a political level. The priority focus should be to maximize productivity of the resource, providing more food with less water, or preferably, more richness with less use of resources. The publication "Factor Four" (von Weizsacker et al. 1997), of the Club of Rome publishes this concept for all productive activities, proposing a goal to double the richness using half the resource. This should be a convenient goal for irrigated agriculture.

[3] Known as rain fed agriculture.

The Government can perform a catalyst role by supplying a bigger support to research and technical assistance programs for irrigated agriculture. As Hall (1999) points out, five issues should be looked upon: (a) the increase of the efficiency of the use of water—particularly important to improve the productivity of big irrigation projects; (b) increase of productivity of small agricultures—particularly relevant to the conditions of the Brazilian semi-arid and to the green belts surrounding big cities, involving effective costs of projects based on partial needs, with special attention to human resources, improvement of qualification and institutional reform, a better extension and support service for infrastructure, for credit and other inputs and access to the markets; (c) development of an integrated approach for the management and use of water—requires multidisciplinarity, holistic vision and the development of tools to help decision makers solve the problems of allocation and ensure sustainable development; (d) training of local human resources for irrigated agriculture—many studies and researches are not adequately published and demonstrated. Pilot fields for testing and demonstrating new and good practices, field days or demonstration days to transfer technologies and workshops will be necessary to maximize the use of knowledge acquired by consultants, universities and research institutions; and (e) support for innovation—this is probably the key for future success in obtaining more wealth with less resource usage. Innovative solutions need to be developed in order to find effective maintenance strategies to improve sustainability and avoid the construction-negligence-reconstruction cycle.

Integrated Management of Water Resources: Democratic and Sustainable Vision

There are certain aspects inherent to water resources, similar to that which happens to petroleum or any other non-renewable and profitable asset, which indicates that water could become a source of economic or military power for a nation. When the demand for water overcomes the supply, some nations will justify their military actions (offensive or defensive) in the name of preserving economic and national security (Schwartz und Singh 1999).

An effective strategy for the sustainability of water resources (SWR) involves the complete preservation of springs which supply water, the rational use of water resources, the equal access to water supply and the direct participation of consumers to select how the resources of water basins would be developed and managed (Miller 2003). The SWR implies that the multiple dimensions (economic, biological, political, spiritual and cultural) of the issues related to water resources be taken into consideration.

The diffusion of participative and alternative assessment methods is a process which should soon be in use under the Watershed committees throughout the country, to the extent that the global water crises deepens and one considers citizen participation to be an important element of Law no. 9433. Thus, one will have to work on a process develop cooperation, the resolution of mutual needs and to develop efforts from all parts in order to increase options of relocation and distribution, in such a way that more intelligent decisions with better benefits for everyone be proposed and approved (Delli Pricoli 2003).

Negotiations based on systemic approaches will inevitably once again present the complexity of the situation. The process of identifying interests and common objective, as well as that of exploring potential actions for solutions, will help to improve the situation if the negotiation processes are based on collaboration through learning and on building a consensus to prevent future conflicts which may lead to worsening the current situation.

The use of systemic approaches is a participatory methodology effective in decision making and in effective solutions of management problems. This methodology can be a useful tool within the basin committees, to increase the participation of the population, taking on the role of generator of information or a simulator, thus becoming a support system to the negotiations.

For Nandalal und Simonovic (2003), the use of systemic analysis has been ample within the planning of water resources. In the integrated management of water resources, the Basin committees will be able to use communication technology and information which come from specific models developed with the objective of simulating grants, the levels of contamination, the prices to be charged from consumers, the availability of the water resources, etc., of a specific basin, based on systemic analysis.

There are already in the country approaches in this direction made by Orellana-González (2006), Orellana-González et al. (2008), Sánchez-Román und Folegatti (2008) and Sánchez-Román et al. (2008).

There is a water blindness[4] that urgently needs to be faced, since without water, we do not have life nor development, nor any protection of the natural habits of which we are dependent upon. If the water is contaminated, it will not be accessible and it is imperative that its quality be recovered through adequate treatments.

The growing demand for water resources is an issue of governance. The access to water can be manipulated through a technological, economic and political point of view. To understand the hidden connections in the world of water resources, including here the virtual water[5] inherent in agricultural commodities which are marketed worldwide, is the first step in solving the problem. A privileged situation which Brazil currently enjoys and which needs to be taken into consideration in commercial negotiations around the world is the amount of virtual water embedded in commodities produced by Brazilian agriculture and which needs to be properly valued.

[4] Expression used as a literary war of expressing the fact that the water resource crises is being ignored, probably because of the illusory perception of abundance.

[5] Virtual Water is the water required to produce, in an intensive way, commodities such as cereals. The importers do not need to use water in the place where the production of the commodity occurs nor where they are consumed. The virtual water is the solution dreamed of by politicians, where the economy finds itself in a situation of water stress. The virtual water is economically invisible and politically silent (Allan 2002).

There are three solutions for the water-deficit: (a) the reduction of the population growth rates; (b) the change of eating habits; and (c) the adjustment of the levels of local development in accordance to the availability of the water resources.

Good sustainability water policies are not attained merely through the use of correct environmental principles. On the other hand, economic principles of efficiency to attain an efficient use of water resources are not the only solution to the problem. Sustainability of water resources is achieved in the political arena. The voices of society, of economy and of the environment will try to impose their own priorities and demands over the water resources in a conflicting way.

Final Remarks

The issues related to the water resources constitute the clearest practical illustrations of the multidimentional characteristics of the environmental problems. To alleviate the worldwide water crises, one needs additional studies on systemic analysis to achieve an adequate planning of the water resources.

Systemic methods have been widely used in negotiation processes, and become even more evident when used in water resources. Yet, all of these methods seem to present a certain complexity to the lay public since they are essentially scientific and heavily based on engineering, with the limitation that they have not been extended to analyze the water security.

The power of voices has been changing over time. Professionals related to the management and the development of policies linked to water resources are resistant to acknowledge the political nature of the creation of policies which regulate the water resources. They prefer to assume that the information on meteorology, hydrology, costs of water distribution and the aggregate value of the commodities by water, will be sufficient to guide policy makers. Political leaders tend to avoid risks, and focus on immediate solutions for everyday problems. More complex problems which can lead to political tension for involving economic and ecological principles receive very little attention in political speeches and few resources to be legislated. Within these complex problems, is the policy of water resources.

There is a paradox that says that the water pessimists are wrong in their bearish positions, yet they are useful as policy tools; and the optimists are right, but their optimism is dangerous as it conveys a sense of security that favors the political positions of “laissez faire, laissez aller, laissez passer” incorrect in this current situation.

Our professional focus, of technicians linked to irrigated agriculture will have to be: (a) promote the reform of exiting works with the objective of improving their efficiency with regards to the use of water rather than building new one; (b) establish national criteria and mechanisms to offer competent technical assistance to all producers; (c) aim investments both on research and on management of the irrigation systems in order to improve the efficiency on the use of water; and, finally (d) aim at increasing agricultural productivity of small farmers. This is the challenge of the professionals linked to irrigated agriculture in Brazil.

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Chapter 2
Water and Health: Global and National Aspects

Ulisses Confalonieri, Léo Heller, and Sandra Azevedo

Abstract Although water is recognized as essential for the appropriate functioning of biological systems and human health, many countries and a large part of the global population are water stressed. The expected changes to the hydrologic cycle brought about by the process of global climate change will aggravate this situation. Almost 90 % of the four billion diarrhea episodes occurring globally each year are linked to deficiencies in sewage disposal and the supply of safe water. In Brazil, the most important public health problems associated to water are: diarrheal diseases, schistosomiasis and other helminth infections, leptospirosis, vector-borne diseases (e.g. malaria and dengue fever) and poisoning by Cyanobacteria toxins. It is suggested, for Brazil, the setting of quantitative goals for reduction in childhood diarrhea in the next 5 years as well as development of integrated indicators for the monitoring of water-and-sanitation-related health problems.

Keywords Climate • Cyanobacteria • Health • Indicators • Infections • Sanitation • Toxins • Water

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Introduction

The importance of water for vital processes and for human health is well known. Water is essential for biological functioning at all levels, from the metabolism of living organisms to the equilibrium of ecosystems. This also applies to human biology, since it is essential to their physiology, comfort and hygiene. However, it is estimated that approximately 1.5 billion people in the world do not have access to good quality water (UN Statistics United Nations Statistics Division 2008). Approximately 80 countries suffer from water stress, defined as the situation in which there is a runoff of rain less than 1000 m^2 $person^{-1}$ $year^{-1}$ (Arnell 2004). The populations of these regions comprise about 40 % of the world's total population.

In 2002, 21 % of the population of developing countries did not have continued access to adequate sources of water (UNSD 2008). The United Nations has the objective, as part of one of their Millennium Development Goals (MDGs), to reduce in 50 %, by 2015, the proportion of the world's population in 1990, without access to good quality water for drinking and without adequate sanitation.

With the prospect of major changes in the hydrologic cycle—at local, regional and global levels as a result of global warming—societies face an enormous challenge with regard to managing water resources and the provision of drinking water. Due to this situation, this article emphasizes the relation between the quantity and quality of water and human health; and the existing challenges for improving the access to good quality water. Some global aspects are briefly taken into consideration, and emphasis is given to national and regional Brazilian problems with regard to water and its health linkages (Fig. 2.1).

Fig. 2.1 Aquidauana River during its flooding in Southern Mato Grosso (Photograph U. Confalonieri)

Water and Health

It is estimated that approximately 10 % of the global burden of diseases is due to the poor quality of water and to deficiencies in excreta disposal and in hygiene (Prüss-Ustin et al. 2008). Almost 90 % of the approximate four billion annual cases of diarrhea in the world (which cause 1.5 million deaths in children under the age of 5) are attributed to deficiencies in sanitation and the provision of good quality water. On the other hand, we know that up to 94 % of all diarrhea cases are preventable (WHO/UNICEF 2006).

Water is related to human health in various ways, the most important:

1. As a vehicle of microbial agents of gastroenteritis, especially due to fecal contamination, or of other infections such as leptospirosis, common in urban flooding.
2. As a vehicle of toxic agents, either natural (e.g. biological toxins, such as those from cyanobacteria; arsenic) or of an anthropogenic origin (other chemical contaminants).
3. As reservoirs of disease vectors, such as mosquitos of malaria and dengue fever and the intermediate hosts (snails) which harbors the worm that causes schistosomiasis (*Schistosoma mansoni*).
4. Direct physical impacts (e.g. flooding in populated areas) or indirect (e.g. damages to the production of food or to health infrastructures, etc.) (Fig. 2.2).

Fig. 2.2 Creek at a flooded area of Aquidauana Pantanal, MS (Photograph U. Confalonieri)

Situation in Brazil

Some classic criteria exist for defining public health priorities for intervention. In general, three main aspects are accepted:

1. Number of affected individuals.
2. Severity of disease processes (measured by mortality and disability).
3. Existence of technologies for prevention/control.

With regards to the health problems related to water, by applying these criteria, we can define the following conditions among the most important:

1. Infantile diarrhea: is still an important cause of death in the country (see page 13).
2. Vector borne diseases: especially, malaria, practically restricted to modified environments in the Amazonian region (with about 540 thousand cases in 2006) and dengue fever, most important in big cities, with about 700 thousand cases in 2008 (incidence in 2007 of 295.7 cases per 100 thousand inhabitants).
3. Schistosomiasis and other soil transmitted helminthiasis: schistosomiasis originates in the fecal contamination (by sick people) of bodies of water such as streams, lakes and reservoirs which contain populations of the *Biomphalaria* genus. It is endemic in the Northeast region and in parts of the Southeast. One estimate points to the existence of eight million carriers in the country. In the Northeast region, 43,759 new cases were diagnosed in 2004 (an incidence of 87.8 cases per 100 thousand inhabitants).
4. Leptospirosis: generally occurs as a consequence of the contamination of water from urban flooding, by urine of sewage rats, which shed the bacteria. It is therefore related to the occupation of urban land in areas deficient in drainage, sewerage and solid waste collection, which facilitates the proliferation of the rodents. Between 1996 and 2005, 33,174 cases were diagnosed in the country. The largest epidemic ever registered in Brazil was in the summer of 1996, in the city of Rio de Janeiro, with 1790 cases and 49 deaths.
5. Cyanotoxin toxicity: in our country, the work of Teixeira et al. (1993) describes a strong evidence of correlation between the occurrence of cyanobacteria blooms in the reservoir of Itaparica (Bahia) and the death of 88 people, among the 2000 intoxicated who presented severe gastroenteritis due to the consumption of water from the reservoir between the months of March and April of 1988. However, the first confirmed case in the world, of human death caused by cyanobacteria toxicity (cyanotoxins) occurred in the beginning of 1996, when 130 chronic renal patients started showing clinical manifestations, after having been submitted to hemodialysis sessions at a clinic in the city of Caruaru, State of Pernambuco, of severe hepatotoxicosis. Out of the total, 60 of these patients passed away within 10 months of the onset of symptoms. Analysis confirmed the presence of cyanotoxins in the water purification system of the clinic and in blood and liver samples of the intoxicated patients (Azevedo 1996; Carmichael et al. 1996; Jochimsen et al. 1998; Pouria et al. 1998; Carmichael et al. 2001; Azevedo et al. 2002).

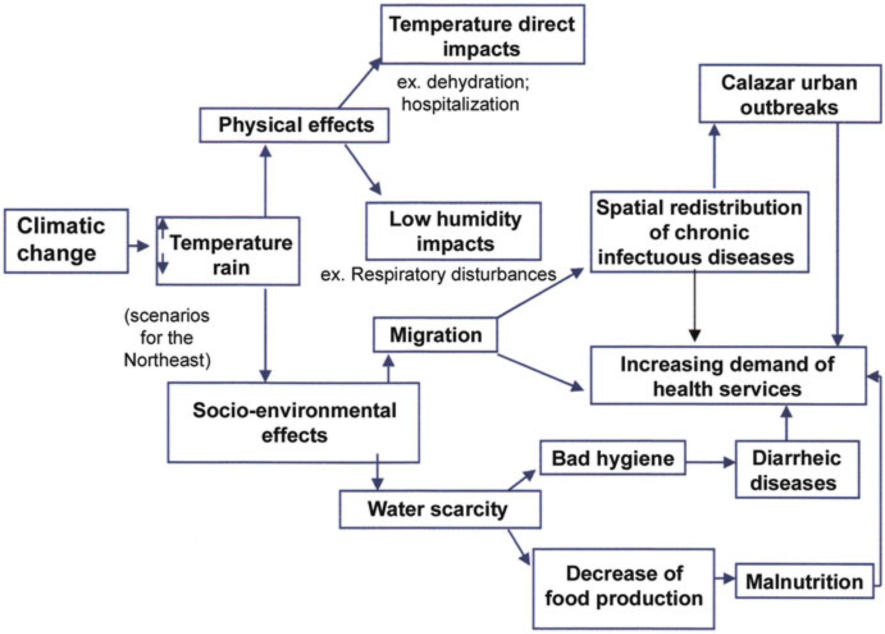

Fig. 2.3 Drought and health in Brazilian Northeast (CEDEPLAR/FIOCRUZ 2008)

6. Complex situations due to chronic shortage of water: it is important to note that the relation of water to the health conditions are generally very complex and mediated by several factors of a physical-geographical, socio-environmental, economic and cultural nature. Figure 2.3 illustrates this, showing how climatic changes can affect the water, aside from other risk factors, and contribute to diseases in the northeastern semi-arid, region of Brazil.

It shows the complex and multifactorial way in which scarcity of water in the Northeast affects health and the medical care systems. Even though high temperature and low humidity have direct impacts on human physiology, most of the health problems derive, indirectly, from socio-environmental processes caused by drought. The most important impacts are: nutritional problems, which are exacerbated by the decrease in the production of food; and the consequences of the migration process brought on by the affected economy (CEDEPLAR/FIOCRUZ 2008). These are the main mechanisms of the spatial redistribution of chronic and, infectious diseases (ex. Calazar) and the cause for the increase on the demand of healthcare systems in the destination of migrants. Although there is a certain adaptive capacity of local populations to drought, mainly through governmental actions of mitigation, scenarios indicate a considerable worsening of aridity in the region, historically unprecedented, and for which society will have to adapt.

Although Brazil has a privileged position in the world, with regards to the availability of water resources (ca. 12 % of the world's availability), there are important regional disparities. In the Northeast region, for example, there are areas in which the availability of water per inhabitant/year is less than the minimum recommended by the UN, of 2000 L (Marengo 2008). One should also consider that the availability of water in Brazil depends largely on the weather, and projections indicate a reduction in the amount of rain in the North and Northeast regions of up to 20 % by the end of the twenty-first century (Marengo 2008). The World Health Organization (WHO) estimated that 2.3 % of the total number of deaths in Brazil (or 28,700 deaths) could be attributed to deficiencies in the quality of water, of sanitation and of hygiene (Prüss-Ustin et al. 2008).

The coverage of water supply services in urban areas of Brazil increased ca. 4.5 percentage points (from 87 to 91.4 %) and most significantly, for the rural population from 9.3 to 25.7 %, with a 16.4 increase in percentage points between the years of 1991 and 2003, according to the statistics of PNAD and the CENSO 2000. This reflects the difficulty in further advancing in the universalization of urban coverage, noting that the population that lacks these services is located predominantly in peripheral areas and in areas of informal urbanization, which indicates the need for the adoption of specific programs integrated to urban development. On the other hand, regardless of the progress in serving the rural population, coverage is still incipient. Furthermore, the data indicates the existence of 12 million Brazilians in the cities and an additional 22 million in rural areas who still need to be supplied by this service, further adding to the demands imposed by the natural increase of population. This coverage by public network of water supply has a greater concentration of municipalities with less satisfactory coverage, in the North and Northeast regions of the country. Although the statistics do not clearly reveal the way in which the water supply occurs, it may be inferred that the supply does not always meet the requirements considered adequate with regards to the continuity of the supply and with regards to the quality of the water, which is reinforced by the irregular financing of the services and by the operational limitations.

As for sanitation, one can also perceive a growth and slight expansion in the coverage of the public network, having grown 13 percentage points between 1991 and 2002 (from 62 to 75 %). Even though an increase of coverage was also indicated for the rural population during the same period, only 16 % of households are actually being serviced; leaving room for discussion with regards to the most adequate technological solution for dispersed populations. In addition, the coverage indicators only supply partial information since they do not indicate the destiny of the wastewaters. Furthermore, there is an issue over the ambiguity of the indicator, since the mere existence of coverage for sewer collection does not necessarily provide for an effective improvement in health and environmental conditions. The collection network in places devoid of interceptors and sewage treatments can even cause an increase in human health problems if the solution previously prevalent, invariably the infiltration of underlying soils by different types of septic tank effluents, was kept in place. In this case, the network ends up concentrating the sewage in the water bodies of urban areas, endangering the population and increasing the circulation of pathogenic bacteria in the environment. The presence of interceptors and treatment plants itself, is no guarantee of human health protection or of water quality of receiving water bodies, if we consider the frequently reduced efficiency of the latter in removing pathogenic bacteria.

With regards to the nature of service, PNSB (IBGE 2000) informs that 4097 (42 %) of the 9848 Brazilian districts have a collective network, but that only 1383 of them have treatment plants (14 % of the total). However, only 118 of them perform disinfection of sewage. Of the total volume of sewage collected, only 35 % receives some sort of treatment, which results in about 9,400,000 m^3 of raw sewage conveyed daily to the bodies of water of the country, taking into account only the sewage collected by network. It is also worth noting the information that 3288 districts with network (80 %) do not possess any interceptor extension, potentially causing the deterioration of the water quality of the receiving bodies of water located in urban networks.

In the assessment of the water supply and sanitation services for the population, one needs to highlight the asymmetries which occur. They can easily be identified according to various dimensions. Aside from the inequality of availability of the service being associated to the location of the household, if urban or rural, it is also surprisingly closely related to income, in other words: the poorer are the most excluded. In addition, studies have revealed that the sizes of the cities and their level of human development are positively related to the possibility of them having greater services of coverage (Rezende 2005) (Fig. 2.4).

Fig. 2.4 Lake in the Pantanal South Region, MS (photograph U. Confalonieri)

Perspectives

1. MDG: there are several interconnections between the Millennium Development Goals and water, sanitation and health. Perhaps, the one which will suffer the most direct consequences will be the reduction of infant mortality Goal 4 of the "MDGs" due to diarrheic diseases, with the improvement of access to sanitation and water supply services. The most specifically related goal, corresponds to Goal 7 (Environmental sustainability), which aims at reducing the deficit through water supply services and sanitation. With this, improvements not only to the levels of health, but also to the conservation of the ecosystems and to decreasing the pressure over the commonly scarce water resources would be attained (WHO/UNICEF 2006; Schuster-Wallace et al. 2008). It is anticipated that Brazil will manage to meet the goal related to the supply of water, but will have difficulties in meeting that which relates to sanitation. In addition, the improvement of water management, with the implementation of better systems, reduces the chances of formation of breeding sites of vector mosquitoes of dengue fever and malaria (Goal 6: Combat HIV/AIDS, malaria and other diseases).
2. Global Climatic Change: the IPCC (Intergovernmental Panel on Climate Change) indicates in its Fourth Assessment Report (2007) the reduction of rainfall, especially in dry tropics, which will increase the number of people living under conditions of water stress. There are also projections of reductions, in the next few decades, of the availability of fresh water in coastal regions as a consequence of saltwater intrusion resulting from rising sea levels (global warming effect). It is also expected that the reduction in flows of river and the increase in temperatures of water will lead to declining water quality, as the dilution of contaminants is reduced less oxygen is dissolved in water, and microbiological activity increase (Bates et al. 2008). As a conclusion, IPCC's work indicates that the changes in rainfall and in temperature caused by global climatic changes will make the provision of fresh water, drainage and sanitation, an even more difficult process. Currently, the management of the water resources has been based on knowledge about stable climates. The policies and regulations on the use of water resources need to include information about regional scenarios of climate changes. For Brazil, studies and the development of regional scenarios indicate the North and the Northeast as the regions which will probably be the most intensely affected by the processes of global climatic change (Baettig et al. 2007; Marengo et al. 2007; Ambrizzi et al. 2007; Marengo 2008).
3. Research, surveillance and monitoring: given the importance of water for human health, sectorial actions are necessary for a more complete understanding of the relation between water and health in the country. Governmental initiatives need to kept, such as the one of 2008, to encourage studies of integrated assessment of human health risk in populations exposed to contaminated water (Sector Funds of Water Resources and Health). Also important are the initiatives for the collection, organization and accessibility of data on water, sanitation and the diseases related to this subject. One should point out, in this respect, the initiative of the

Ministry of Health (General Coordination of Environmental Surveillance) and of the Oswaldo Cruz Foundation, for the creation of the digital atlas "Water Brazil". Containing indicators on health, water quality and sanitation, on a municipal level, in the entire country, the atlas allows for a visualization of water supply problems, standards of consumption and the epidemiological profile of waterborne diseases (http://www.aguabrasil.iact. fiocruz.br).

4. Universalization of sanitation services: the need to increase the coverage of water supply and sanitation services, aiming at placing Brazil at the level of development pursued by the country and intensity the impact on populations health, is very clear. There are big challenges to reach a situation of universality and equity for services, ensuring access to the entire urban and rural population, to the quality of services and its support over time. The inclusion of populations from the periphery of large cities and rural areas, the assurance of safety of water supplied and the implementation of means of adequate disposal of the residues consist of important challenges. Real progress in this direction will require a combination of efforts, in other words, a public policy adequately designed and implemented, the enabling of financial resources and the improvement of the management of the services. These initiatives, effectively, have the need for an integrated adoption, eliminating the idea that only financial resources are needed to overcome the problems in this area. In a way, there is an acknowledgement of the importance of prioritizing the actions of sanitation and that the success of the public policies, require the adoption of a long term integrated vision, acknowledging the role of different social actors with the new federal legislation approved in the Country (Brazil 2005, 2007). However, a political desire of overcoming these predicted obstacles for this progress will be indispensable for the success of the implementation of these legal instruments.
5. Protection of human health from exposure to toxic agents: while the cyanobacteria are natural components of any aquatic ecosystem, paying attention to the occurrence of these microorganisms in public water supply is relatively new. The increase of eutrophication of reservoirs has been produced mainly by the discharge of domestic and industrial sewage from urban centers and by the diffuse pollution originating in agricultural regions. This artificial eutrophication produces changes in the water quality, including the increase of the incidence of blooms of microalgae and cyanobacteria, with negative consequences on the efficiency and the cost of water treatment. In our country, the problem of blooms is intensified by the fact that the majority of the water supply reservoirs present the necessary characteristics for the intense growth of cyanobacteria throughout the year. It is impossible to consider the cyanobacteria as pathogenic microorganisms in the classical sense, because although several lineages of different species of this organism can produce bioactive and toxic secondary metabolites for cells of several animal groups, a large part of these compounds are only liberated into the water after the cell lysis of cyanobacteria. The quality of water may be more compromised by the presence of toxins in their dissolved form, than by viable forms of cyanobacteria that, potentially, should be in the most part removed during the conventional treatment of water. In turn, these can lead to the

rupture of the cells of these microorganisms due to the use of chemicals during the several stages of this process. Cyanobacteria are also often associated to the production of compounds that provide taste and odor to drinking water. Although these compounds cannot be considered toxic, their presence cause concern to health authorities, seeing that frequently it results in the population rejecting the potable water, leading them to seek alternative sources of water supply, thus creating an added risk to public health. Proven records of the occurrence of toxic blooms in Brazil began in the 1980s. Aquatic environments located in areas of strong anthropogenic impact had a high percentage of dominance of cyanobacteria and occurrences of blooms. In at least 11 of the 26 states of Brazil, toxic species of cyanobacteria have been identified, of which the majority of the records are from multiple use reservoirs (Azevedo 2005). In many of the cases, the cyanobacteria which cause damage disappear from the reservoir before health authorities consider the bloom as a possible risk, for they are usually unaware of the possible damages which result from the occurrence of cyanobacteria blooms and, therefore assume that the common water treatments are capable of removing any potential problem. Yet, several cyanobacteria toxins are, when in a solution, not removed by means of a conventional treatment process, being even resistant to boiling. With the frequent appearance of cyanobacteria blooms in public supply reservoirs, environmental authorities try to, in general, control the blooms by applying copper sulphate or other algaecides. This method causes the lysis of these organisms, releasing the toxins often present in cells, into the raw water of fountains. Such actions can cause severe exposure to toxins. In addition, there is evidence that populations supplied by reservoirs that contain extensive blooms can be exposed to low levels of toxins for prolonged periods (Hilborn et al. 2008). This prolonged exposure should be considered a serious health risk, since the microcystins, precisely the most common toxins of cyanobacteria, are potent promoters of tumors, and therefore, the continuous consumption of small doses of hepatotoxins can lead to a higher incidence of liver cancer among the exposed population. The chronic or episodic exposure to cyanobacteria toxins is, without a doubt, the main cause of human exposure to these compounds, especially orally, through the supply of water. On the other hand, studies developed in Brazil by Magalhães et al. (2001) and Magalhães et al. (2003) demonstrate that fish (tilapias) and crustaceans are also capable of accumulating microcystins in their muscle tissues, sometimes even at levels way above the limit recommended by WHO, which represents a serious risk for the population that consumes this fish. The impacts causes by toxic cyanobacteria in Brazilian aquatic environments have been intensified by fish farming in tank networks, even in multiple use reservoirs which are used for public supply, and by the intensive cultivation of shrimp in reservoirs and estuaries.

6. Heavy metals and organic micro contaminants: the concentration of heavy metals in the environment occurs due to anthropogenic releases associated with the effluents from metallurgical and chemical industries or mining activities that target in most cases, aquatic environments. Only a few years ago, did the scientific community start to pay attention to human exposure to certain heavy metals, such as

methyl mercury (MeHg), cadmium (Cd) and lead (Pb), among others that, even in moderate and continued doses can cause irreversible toxic effects to human health, especially to the central nervous system. The aquatic systems are particularly sensitive to pollutants because they have longer food chains, which may favor biomagnification phenomena, in other words, the increase in the concentration between two successive trophic levels. Reservoirs are environments which are more susceptible to contaminations by metals and other micro pollutants, due to their mobilization from flooded soils. Tropical dams are again, examples of this (Kehrig 1999). One of the important potential consequences of damming is the intensified production of methyl mercury, associated to the anaerobic degradation of flooded organic matter, as has been amply documented in reservoirs located in regions of temperate and boreal climates (Guimarães et al. 2000). In tropical reservoirs, it is expected that the methylation process of Hg be favored due to: the elevated and irregular temperatures, the intensified microbiotic activity and due to the frequency and duration of the stratification of the water column, with the development of reducing conditions in the hypolimnium. Most recently, the problem of environmental contamination by organic micro pollutants (pesticides and polychlorinated biphenyls or PCBs) and polycyclic aromatic hydrocarbons (PAHs) are also being investigated in aquatic systems. The majority of these compounds are banned from being used or are controlled, and their production is controlled in most developed countries in the world. Despite DDT (dichlorodiphenyltrichloroethane) being prohibited in most developed countries, this product was, has been and probably will continue to be used in the control of vector diseases by insects and in the control of agriculture pests in underdeveloped and developing countries. The PCBs, widely used in large electric transformers in the past, also had their production and use restricted, yet some equipment still uses them. However, for tropical environments there is very little information regarding the behavior and the final destiny of this class of substances (Fig. 2.5).

Recommendations

It is suggested, as an element to guide public policies, that goals be established to reduce morbidity and mortality from diseases related to lack of access to good quality drinking water. In this sense, by the direct relationship with the quantity and quality of water and with the adequate disposal of excreta, infant diarrhea stands out as the greatest problem and as an adequate indicator, the reduction of which is possible through easily executed interventions. One proposes the establishment of a goal of reducing the percentage until the year 2014 (period of 5 years) in mortality cause by diarrhea in children under the age of five in Brazil.

Given the multisectorial nature of the "water problem" and its close links with health, one suggests the development, refinement and implementation of a composite index related to "water/health/environment/society", capable of serving as a tool for the monitoring of access, of quality and of use of water and their relations, as specific

Fig. 2.5 Storm over Belo Horizonte, MG (photograph U. Confalonieri)

indicators of health. The idea is to have a quantitative indicator which allows for comparisons and which can be applied at different levels (ranging from communities to national levels), as a comprehensive instrument, capable of capturing the relations between social life, water, and the impacts of their uses in health. A possible alternative would be an adaptation of the "Water Poverty Index" (Sullivan 2002; Sullivan and Meigh 2007; Lawrence et al. 2002).

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Chapter 3
Water and Economy

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Abstract This paper addresses one of the important issues that face water against its economic aspects: the use of economic instruments to manage water resources. First, historic and conceptual issues are considered. In a second part, the Brazilian water resource legislation is analyzed. In a third part, the water user pays principles (UPP) and water polluter pays principles (PPP) are considered, with their contributions towards adoption of economic instruments for water resources management. Finally, a comparison between these principles and the reality of the current Brazilian water resources management is presented, showing that there is still much to move.

Keywords Benefit-cost analysis • Cost-effectiveness analysis • Polluter pays principle • User pays principle • Water charges • Water resources management

Introduction

This article addresses one aspect of the vast subject of "water x economy" namely: up to what point are the multiple uses of freshwater, and especially the discharge of effluents into our watersheds, affecting the economic value and the prices of this natural resource, which up until a few decades ago, was considered a "free good" or a "good of free access" for its several uses such as: a productive input, to dilute and

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assimilate effluents, supplier of the so-called environmental amenities.[1] Today, the situation is totally different.

The understanding of this phenomenon is immediate if we pay attention to the data collected and worked upon by Williamson and Milner (1991), who supplies us with an enlightening historical overview. According to the authors, in the 200 years of Industrial Revolution up until 1990, the planet's population practically increases by six times (going from one to six billion inhabitants), while the Gross World Product, except for the issue of index numbers, was multiplied by approximately 33 times. This last data represents, in average, a doubling of population every 40 years. Taking into consideration the property of geometric progression of ration by 2, in which the last term of the progression is greater than the sum of the preceding, in turn implies that, in estimated terms, during the period of 1990–2030, the planet will experience a pressure in terms of: use of space, use of natural resources and discharge of effluents—greater than that of the previous 200 year.

This phenomenon of exponential growth—typical since the Industrial Revolution, but absolutely new to the History of the Planet—is at the core of Boulding (1966) Seminal paper on the economy of the cowboy versus the economy of the spaceship: we are no longer in the time of the economy of the great plains and of the abundance of natural resources; the natural environment of the economic system is no longer an unlimited reserve of raw materials and environmental amenities, nor is it a septic tank in which we can simply dump and recycle all the debris at no cost. In addition, one needs to understand that the problems of stress and environmental degradation are not a result, in itself, of the use of natural resources and of the waste emission by humans, for such use and emission have always occurred. The problems results in fact from the volume, with regards to nature's capacity to sustain and assimilate the increased quantity of emissions: environment has become scarce and needs to be "economized". And, similar to what occurred with fertile lands—the first natural resource to become relatively scarce to needs—the natural assets will follow the same pattern, in an increased fashion, at a price based on scarcity. To make matters worse—actually perfectly understandable based on the exponential growth of population of production and of problems, as Mckinney et al. (2007) indicate—we are no longer experiencing a "local" degradation of our rivers and of our metropolitan air caps, we are in fact at a level where the problems deriving from over exploitation and pollution of natural assets have reached a global scale: compromising of the ozone layer, global warming and climatic change, decrease of biodiversity and of forest areas. In the majority of the advanced countries, especially in Western Europe, the management of the water resources is being made within the trend which became known as publicizing of water. This phenomena[2] is part of a greater context of tendencies of environmental policies which are characterized by three main components: (1) a strong and growing intervention by governments, featuring an environmental ownership by the states; (2) diversification of policy instruments, increasingly using among others, two economic

[1] For a comprehensive review of issues related to waters, see Rebouças et al. (1999) and Tundisi (2003).

[2] The exposure is also true with regards to the administration of air pollution.

instruments, that of charging for use (the so called User Payer Principle—UPP) and the tradable pollution permits; and (3) implementation of environmental policy, in general within an analytical framework called Cost Effectiveness Analysis, which aims to achieve quality goals of receiving waters, an objective almost always socially agreed upon at the lowest cost to society as a whole.

The Environmental Policy outlined above is the culmination of a process which lasts over one hundred years and started with court disputes at the end of the nineteenth century and the first half of the twentieth century, going through the famous Command and Control Policy, since the end of World War II and in effect, exclusively, until the end of the 1970s.[3]

Charging for the Use of Water

When it comes to charging for the use of water, it is common to hear the allegation that water is already paid for by the consumer. The answer to this objection will lead to the conceptualization of four prices of water. In a typical large city, an urban consumer pays two prices for the drinking water he consumes:

1. The price corresponding to abstraction service, treatment for purifying plants and distribution of treated water to the consumer.
2. Price corresponding to the sewage service, that is, the collection of sewage from the consumer, transportation and final destination of the used water to the bodies of water.

In this procedure, the water body—weather it's a source of resource or a cesspool of waste—is accessible to all, and free of charge. In the early days of development and of urbanization, with a low per capita income and low population density, these two prices for water were perfectly functional, covering the costs society had with regards to the provision of water supply and sanitation. Gratuity of water in nature was possible because it was abundant in relation to needs; all other uses (hygiene, fishing, navigation, irrigated agriculture, etc.) were viable, not being influenced by urban use, since the capacity of the water bodies and their assimilation ability for all the uses was sufficient, at no cost.

However, as economic development, increase of income per capita as well as population growth occurred, the need for feeding the population through intensified irrigated agriculture, through the making of a series of consumer products for the modern society, and the need for transportation of these products etc., was also generated. In the starting phase of this process of economic growth, as the discharge of sewage back into the bodies of water exceeded its capacity of self-purification, it caused such a severe degradation in the quality of water that it compromised balneability, fishing and even the supply of drinking water which then became more expensive due to the increase of treatment costs. At a later phase, as the removal of

[3] For a comprehensive review on this progression, see Lustosa et al. (2003).

water became excessive in relation to the carrying capacity of the water bodies, it generated problems related to quantity, made evident by sudden conflicts over the use of water. Anyway, the fact is that the bodies of water in the vicinities of the large development centers have become scarce, both with regards to being of insufficient quantity as well as for its degraded quality; and all of its uses, with free access to everyone at no cost, is no longer possible.

It is in this situation of being at the limit that society can opt for governmental intervention, establishing state ownership of the resource, which then ceases to be of free access—with the objective of rationing and streamlining its uses. On the other hand, a system of allocation of quotas or the granting of rights to uses of water can be implemented, as a way of normatively reconciling the availabilities with the uses of water.

This is a management tool incorporated to the so-called command-and-control class.

On the other hand, the User Pays Principle can also be implemented as an economic tool to promote the rationing and the streamlining of use, aiming at the same conciliation among availability and use of water, by means of economic incentives, implying in two additional costs for water:

3. Price corresponding to the abstraction and consumption of water, aiming at rationalizing consumption, enabling even investments in sparing devices or in devices which increase water availability.
4. Price corresponding to discharge of sewage in rivers (the most famous being the Polluter Payer Principle), also in a sense of slowing its launching[4] and enabling investments in treatment plants for example.

The payment of prices 1 and 2 are not a novelty in the Brazilian scenario. One pays the concessionaries of water supply and sanitation for their services and one pays for the water supplied in irrigated perimeters. In all cases, once seeks to maintain the financial health of concessionaries so that they can deal with the costs of providing the services and deal with the costs of expanding their services in order to meet the growing demands.

Prices number 3 and 4, are in fact a novelty brought about by the modern policies of water resource management and integrate the so-called User Payer Principle (UPP), becoming an increasingly used instrument in a sense of enabling the several uses of the bodies of water which have become scarce. These prices are the main conceptual framework of the billing system for uses of water, to which this article refers to.

Brazilian Legislation of Water Resources

The trend of publicizing water echoed within our country, culminating in the enactment of the Federal Constitution of 1988, in which state ownership of water was established (art. 20, I and art 26, III, waters as assets of the Union or of the federated units). Based on this, several states of the federation progressed in a notable way, as

[4] If the tariff per unit discharge is sufficiently high, it will cost less for the agent to treat the sizeable portion of the sewage and pay for the residual pollution, than to pay for the total discharge of the generated sewage.

they enacted their State Constitutions and the respective laws regarding the management of waters under their domain, to incorporate in the management policies, the use of billing for the water resources (see, especially the laws of Sao Paulo—Law 7,763/91 and the law of Rio Grande do Sul—Law 10,350/94). Finally, Federal Law 9,433/97, giving shelter to these pioneering laws, also incorporated billing as an important tool in the management of waters. Federal Law 9,984/2000 (National Water Agency—ANA) is, undoubtedly an essential complement to Law 9,433.

The system proposed for Brazil, within these laws, places the country in the path of implementing a cost-effective policy, partially inspired by the German experience of the Water Companies of the beginning of the twentieth century and by the French system of basin committees/agencies, nationally established as of 1964. The French water resources management system is a decentralized and participatory model, that operates through the committees of water basins; true “water parliaments” responsible for managing the waters of the respective basins within a condominium perspective with the technical support of the basin agencies.

In the legislation being implemented, we clearly distinguish through the classification of bodies of water into categories of quality with regards to how they are expected to be used, the establishment of standards of quality with goals determined by environmental authorities and expressed by society, which need to be gradually achieved by the respective basin committees. In order to achieve this, the committees need to use several management tools, among them: (1) Basin Plans—planning tools for the interventions required to achieve the goals; (2) Guidelines for Licensing—aiming to reconcile the several uses of water in the basin; and (3) Charging for the use of Water Resources (the so-called User Payer Principle—UPP)—an excellent economic instrument, which aims at inducing a more moderate and rational use of water resources and at financing the necessary interventions foreseen in the basin plan.

In 2002, the country began charging for the use of water. This first implementation of the User Payer Principle occurred in the basin of the Paraiba do Sul River (where the main river, for which the basin is named after, is of federal domain) through the Committee for the Integration of the Paraiba do Sul Water Basin. In 2006, the PCJ Committee started charging for the use of water in the Piracicaba, Jundiaí and Capivari rivers. It is important to note that the Brazilian experience, with regards to pollution, differs from the French model which inspired it—since the charging is currently based on the components of the organic load only (the Biochemical Oxygen Demand—BOD). The non-organic load and the so-called “toxic-load” (heavy metals, etc.) will probably still be dealt with for some time, through the emission standards (Command and Control Policy).

The User Payer Principle (UPP)

Within the framework of a cost-effective Environmental Policy in the area of water resources, the charging for the use of water, as an instrument of incentive, almost always prevails: the so-called User Payer Principle (UPP). UPP encompasses the charging for abstraction of water from the source (which does not have a proper name), for the consumption[5] and the billing for the discharge of effluents (the "old" Polluter Payer Principle—PPP).

Billing for Water Abstraction

In order to maintain the discussion within its essential aspects, we will examine a hypothetical case with only two groups of users. Let's consider the case of an area which has its agricultural (irrigation) and urban supply made possible by a stretch of the river that runs through the region. Figure 3.1a shows the demand for raw water, per period (i.e. monthly), of the agricultural sector for irrigation purposes (Da). Figure 3.1b shows the demand for the same period, of the Water Supply Company for purifying plants and distribution to urban residents (Du).

If the available flow rate during the period, for supply and irrigation, is superior to the sum of Q1 + Q2, the abstraction for this period will correspond to this sum, in which the abstraction will be free of charge for both groups of users. Makes sense, if there is a relative abundance of the water resource, there is no reason to restrict demand by imposing a cost for the abstraction of the raw water.

Yet, if the available flow rate during the period is inferior to the sum of Q1 + Q2, the maximizing of the Total Net Social Benefit (area above the demand curve) requires that the consumption of both groups be contained up until the point where the Marginal Net Social Benefit is equal to both consumers. This can be obtained through the charging of a price (specifically the charging for water abstraction) equal to TT′ in Fig. 3.2, where the curves of the Total Net Social Benefit of both consumers are placed one against the other, in comparison to the fixed limited availability (periodic availability flow) of raw water by the river. As can be seen on the graph, any point of consumption other than AT, for agricultural consumers (irrigators) and GT, for urban consumers, results in a Total Net Social Benefit inferior to the maximum, in view of the fact that the marginal benefic achieved by any group that increases its consumption is inferior to the marginal benefit lost by the other group.

We can make two observations. First, Fig. 3.2 serves to explain the seasonality of billing for water abstraction, even in contemporary situations. What happens is, in certain regions, during rain periods, the river can be considered to be abundant with regards to the total demand, and therefore, configures in a situation where there is no need for billing for water abstraction to slow down consumption. Billing for abstraction is only applicable in drought periods, when there is indeed a situation as depicted in Fig. 3.2. Secondly, the type of analysis performed above is identically applicable to the cases of subterranean waters, in other words, in the event that the

[5] This is why, many times, the term User Payer Principle is used to designate a billing for abstraction and consumption of water. Nevertheless, to us it seems more appropriate to maintain the allocation of UPP to encompass abstraction, consumption and the discharge in effluents, because the user of a water resource is both he who abstracts and consumes, as well as he who discharges into effluents.

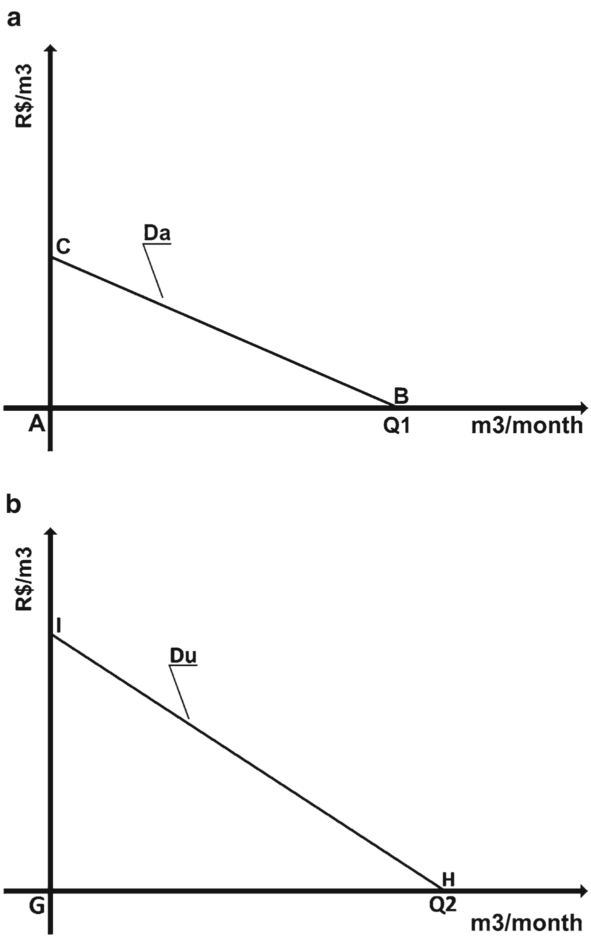

Fig. 3.1 Billing for water abstraction

total demands, supplied by abstraction, is inferior to the recharge of aquifers, there is no need to bill for anything; in the opposite case, charging would be justifiable.

Some practical observations are necessary. For the implementation of the efficiency criteria described above, evidently one needs to have the water demand curves for each sector involved. These water demand curves depend on the determination of a “production function” for the water, in other words, a function which associates the several quantities of raw water abstracted to the production of the sector. Once this is established, it is possible to, via optimization of microeconomic analysis, determine the quantities of water each sector will abstract and the several possible prices.

The pure and simple implementation of the efficiency criteria can lead to deadlock situations, where for example, the demand of a group can be so high (the demand of the supply company for example) with regards to another group

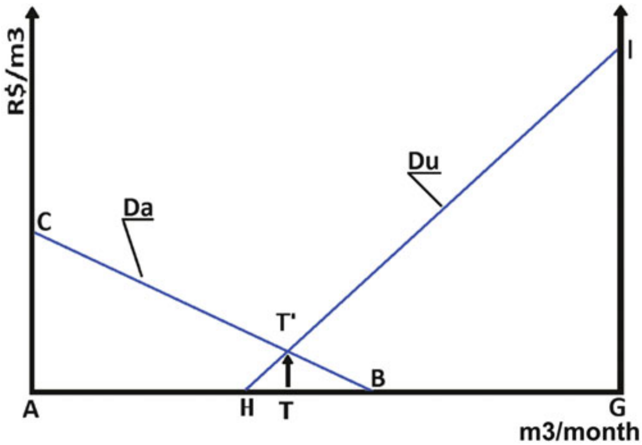

Fig. 3.2 Seasonality of billing for water abstraction

(hypothetically let's say the irrigators), that the determination of an efficient price, would lead to the impracticability of one of the sectors for being so elevated. Thus, rarely are production functions and demands for water for all sectors calculated, instead, one chooses to use prices determined by approximation/negotiation. These prices are generally agreed upon, in order to partially or totally fund the interventions within the basin destined to increase the use of water or better utilize it (flow regulating dams, canals, etc.).[6]

However, for planning purposes by a centralized authority or for the purposes of negotiation at a basin committee level, it is essential to at least count on the demand function of the agricultural sector (irrigators), due to the level of consumption of the sector, as well as its economical importance.[7] A demand curve of the agricultural sector calculated at a reasonable approximation can demonstrate the level of subsidy needed for the sector, as well as the level of coverage of the financing of the necessary construction for the implementation of the irrigation (it would be most convenient if the tariffs could cover at least the operational and maintenance costs, partially contributing to the capital costs).

The imposition of a price for the companies that supply treated water, charging for abstraction of raw water, raises a relevant issue. As the charges for use is passed on to the urban consumers, in the final tariff (and this would need to be done…) the water company may face problems with regards to profit. In reality, although the company is a natural monopoly, it is not free from facing, on behalf of the consumer, a variation in the price of demand. If this variation is equal or greater to one, the company may, after passing on the billing, experience a decrease in income, for

[6] A more ample and profound review, including the issue of billing for discharge in effluents can be found in Hartmann (2008).

[7] The classic reference with regards to the demand of water for irrigation is James and Lee (1971).

a similar production of something smaller. Given its cost structure, where fixed prices predominate, this could compromise its profitability.[8]

The Billing for Discharge of Effluents (PPP)

In Fig. 3.3, the segment Od represents, in terms of percentages, the total of emissions/year of a given polluter (BOD for example) at present, in a given watercourse. Through hypothesis, the use of the so called dispersion models allows us to establish that, in order to achieve the level of quality established at the time of the framework, it is necessary to annually eliminate the percentage of Oc. Seeing that, in the beginning of the process, a goal of such nature would be very ambitious, it is broken down into several partial goals to gradually be achieved in successive periods of 4 or 5 years. Thus, we would have as an example, the goal Oa to be achieved in 5 years, Ob in 10 years and finally, Oc in 15. Once the abatement cost curve is drawn (long-run marginal cost), CMg—that organizes in a growing manner, the cost of abatement of the several polluting sectors[9]—it is possible to, through successive and growing tariffs over time, achieve the established goals. Thus, the tariff of OT1 $ton-year allows for the abatement of the proportion Oa and, thereby achieve the first partial

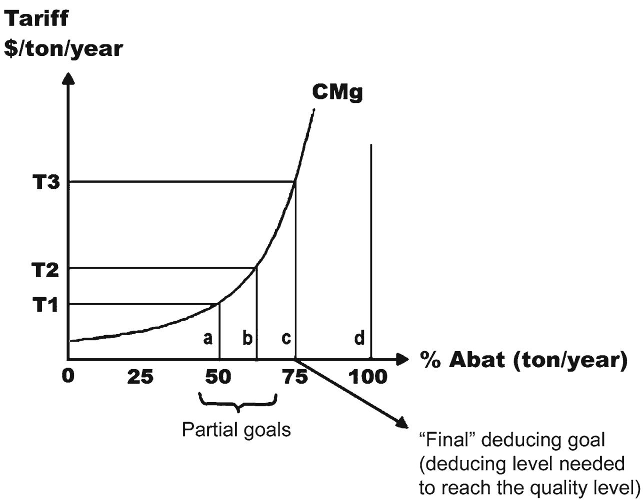

Fig. 3.3 The PPP in the context of a cost-effective policy to combat pollution

[8] Obviously, these effects will occur when the price charged becomes significant enough to result in a deduction in use of water; at this moment, Brazilian experiences have not reached this level.

[9] Such curve is construed by the basin's agency, based on information on abatement technologies commercially available (in general, end-of-pipe).

goal. Actually, given this tariff, all polluter agents whose pollution abatement cost is inferior to the tariff (part Oa of the CMg curve) will prefer to abate pollution rather than discharge and, therefore pay the tariff. Other polluters however, such as those on part ad, whose abatement cost is superior to the tariff, will opt for paying the price OT1 and continue to pour their effluents. Upon the conclusion of this "program" (which in general takes a few years), one can carry on to a second phase, using a higher tariff OT2. In this case, it will now be those in category Oa, who will prefer to abate (in addition to those in Oa who will evidently continue to abate), while those in category Bd will pay a higher price, but even so, will not yet treat their effluents; and successively until the ultimate goal is achieved.

The description above illustrates the incentive aspect of charging for the use of the resource. In reality, rising prices induce; they urge the user agents to "moderate" their uses until desired levels are achieved. But, they also serve to illustrate the additional aspect of the potential funding for rebates to be made. Looking into the case of the first phase mentioned above: the use of the tariff of OT1 $/ton-year. The "payers" of part ad, who produce an income OY1 x ad, enable the committees/agencies to contribute the financial resources (or at least part of it) so that the "abaters" of part Oa can perform the necessary investments to the respective abatements. The same logic is applicable to the subsequent phases.

In the decentralized and participatory system being implemented in Brazil, this aspect of a financing tool allocated to the tariff is very clear. And more, the committees, as true "parliament of the waters" as they are, will possess jurisdiction to decide on which type of financing should be granted, weather at market interest rates, at subsidized interest rates or at no cost. It is not an exaggeration to say that the conjunction of these two aspects, that of an incentive tool and that of financing, available to an agency representing society (the committee) represents an important promise with regards to the recovery of the quality and the quantity of our watercourses, providing an effective possibility of reconciling economic growth with the protection of one of the most essential natural resources, known to be one of the most complex "trade-offs" of contemporary economy.

This cost-effective approach raises theoretical-practical issues of extreme importance that can be better assessed when analyzed through a practical implementation such as the one found in Cánepa et al. (1997). However, some general issues are considered below.

In the case of a decentralized decision, through the basin committees, the discussion on the level of billing x abatement goals is a crucial interaction item of the basin committees/agencies. In fact, the explanations on the several alternatives of abatement, the respective levels of incentive billings, the financial repercussions on the agents, the environmental repercussions on the levels of quality of the bodies of water and on its more or less speedy approach to the goals established in the framework, the possible inter-sectorial subsidies, etc., are all duties of the agency in order to support the discussion and the decision being made by the committee, who, despite being true "parliaments of water", cannot make decisions without the technical input supplied by the respective agency; in the case of a centralized administration, directly by an environmental authority, all the above items should also be looked upon, but by a smaller group of decision makers.

Curves, such as the one on Fig. 3.3, have a first characteristic, a relevant technological fact which is: the accentuated exponential nature, especially in the levels of abatement which are close to 100 %, in other words, the exponential growing costs of abatement of pollution as the levels of abatement increase. This fact helps to explain a very important consequence in terms of public policies dealing with pollution combat. In general, a community will be able to engage in a depollution program, at relatively low costs during the first 10–15 years, and thus use the incentive tariff. Nonetheless, as we approach the high levels of abatement, required by the increasing scarcity of the environment and by the quality goals established in the original framework, the tariffs will also have to, in order to continue to be an incentive, be exponentially readjusted: the inescapable reality of marginal cost curves like these is that, based on currently known technology, the relative price of recovered environment increases disproportionately. In order to deal with this phenomenon, there are two complementary paths: in the first place, to increasingly use pure tariffs for financing of the interventions, maintaining values that can be assimilated by the polluter agents, though obviously delaying the process of meeting the goals set in the Framework[10]; secondly, to stimulate technological innovation, making the marginal cost curve "turn" clockwise.

In any concrete case of water resource management, evidently, there is never one unique problem being "attacked". Therefore, almost always we have to face a fight in several fronts: BOD_5, suspended solids, toxic load, nitrogen, etc. Then, in this case, we need to build curves similar to those in Fig. 3.3, for each pollutant. However, two things can occur here: on one side, the abatement technologies and their respective costs are independent among all pollutants; in this case, curves similar to that of Fig. 3.3 need to be construed for each pollutant (where one can even have a reordering of the "levels" of the several sectors); on the other side, the abatement technologies, with their associated costs, can be combined for two or more pollutants (for example, the technology that abates BOD_5 also abates suspended solids). In this case, one needs to make a proportional allocation of the total cost between the two or more interrelated pollutants, so as not to fall into double counting of the cost and unnecessarily inflating the tariffs.[11]

The informational requirements of this entire system are very amicable. The committee/agency or the environmental authority basically needs three sets of data: estimate (followed by registration) of pollutant sources and respective levels of discharge, operational and investment costs of the alternative abatements commercially available and models of dispersion/assimilation of pollutants in the receptor environment. Several studies in Brazil can already count on the above mentioned sets of data for the majority of our watercourses.

[10] Evidently, it is possible to initiate the pollution abatement process using, as of not, pure financing tariffs. This implies in specific agreements with the productive sectors that will receive the funds raised and perform the treatment for one application in the same hydrographic basin of Rio dos Sinos (see Pereira et al. 1999).

[11] The case of the Rio dos Sinos basin is enlarged in order to contemplate this possibility in Cánepa and Pereira (2001).

The Brazilian Experience in the Management of Inland Waters

Even though the Brazilian legislation has, as we have seen, all the ingredients to accommodate a water resource management within a cost-effective framework, the experience up until now, 15 years after the enactment of the main state laws and 10 years after the federal law on waters, leaves much to be desired, mainly because the process of deployment and implementation is extremely slow and timid:

1. Only one pollutant is considered in the PPP (BOD).
2. The tariffs have no incentive characteristics, they are only financing tariffs, of sharing the agreed intervention costs.
3. Moreover, tariffs, even those for financing, could fall into the category of cost-effectiveness; but, that is not what happens, for interventions are established after the tariff is collected, through "candidate" projects which have no relation whatsoever to the leveled curve of Fig. 3.3.
4. The environmental agencies, still guided by the "old" policy of Mandate—and—control, have not absorbed the radical novelty of the new legislation. There are plenty of lawyers in the area of Environmental Law who ensure that the new legislation is complementary to the former one. Now, if the old policy of Mandate—and—Control, with its emission standards for all sectors is maintained, there is absolutely no need for the charging for the use of water resources (in the best case scenario, only the abstraction of water would be charge for).

The delay in implementing a cost-effective management system of environmental resources such as air and water—being very late in comparison to what has already been achieved by advanced countries—leaves our country in a very serious moment. As was seen in the beginning of this article, the current situation in the world is one of emergency, of true global problems, which also need to be faced. Now, to do this while we have not even managed to even fully consider the issue of local/regional natural asset is a tremendous handicap.

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Chapter 4
Conservation and Reuse as Management Tools to Mitigate the Billing Charges for Use of Water in the Industrial Sector

Ivanildo Hespanhol

Abstract Scarcity, water conflicts, water charges, the response from the financial market to conservationist enterprises and the appeal to a positive environmental image stimulates the industrial sector towards implementation of extensive programs on environmental management. A recent survey on the Brazilian environment has shown that a large amount of companies, particularly from the industrial sector, has taken environmental management as the basic tool for promoting corporative sustainability. The main purpose of the survey was to identify the categories of practices adopted by the productive sector to reduce the intake of natural products and to produce fewer effluents. The survey concluded that most of the industrial and agricultural companies surveyed have adopted goals for demand management, water reuse and effluent recycling. It also showed that most of them have built wastewater treatment plants or are implementing actions to reduce the emission of effluents. In order to evaluate the benefits brought about by the practice of water reuse within the industrial sector, it has been performed a simulation by collecting data from 2311 industries operating within the State of São Paulo, taking into consideration water charges related to water intake and effluent disposal, according to the local legislation. Results have shown that by performing 60 % of industrial water reuse, an amount perfectly feasible within the largest majority of industries, will bring about a significant reduction of water charges. However, full adoption of the water reuse practice in Brazil is still far away from being attained at all. It will occur in a large scale only after a strong political decision is made and a comprehensive and realistic legal framework is enacted, which can be effectively implemented by the watershed committees.

Keywords Environmental management • Industrial reuse • Water charges • Water conservation

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Introduction

Scarcity and the increase of conflicts over water use have led to the emergency of conservation and reuse as formal components of water resource management. Some of the benefits inherent to the use of recovered water for beneficial purposes, as opposed to the disposal or discharge are: the preservation of high quality sources, environmental protection and economic and social benefits (Asano 1998).

In the industrial sector, the accomplishment of the much desired sustainable entrepreneurship depends upon the level in which the conservation of natural resources is done, particularly of the water resource, mainly through the implementation of environmental management concepts, eco-efficiency of the productive process and the use of clean production practices.

The industries have accepted the challenge, and their commitment can vary in several levels, depending upon their environmental consciousness. On a first phase, they can be dedicated to environmental control on the outputs only, in a second phase, the integration of the practices of environmental control together with industrial processes, and finally, the integration of environmental control in the entire company (Donaire 2007).

The financial market has continuously responded to the companies who promote such conservation practices by aggregating value and safety to their assets and providing greater returns to investors.

Aside from these internal characteristics, several other exogenous constraints limit sustainability of the industrial sector, both with regards to the economic aspects as well as the aspects associated to the availability of infrastructure for an adequate production. These factors which mainly appeared at the end of the last century, as shown below, are constraints imposed by international markets and nationwide legal and economic restrictions.

However, faced with the new factors and concepts that promote the role of industries through the implementation of clean management practices, the industrial sector has been demonstrating, in the last decades, that the challenge of producing while sparing natural resources is being satisfactorily met through the use of new technologies and the adequate implementation of modern environmental management concepts.

Brazilian Industry and Environmental Management

A recently held survey on the Brazilian environment (Environmental Management Analysis, Yearbook 2007) demonstrated that the corporate world, particularly the industrial sector, considers environmental management an essential tool for corporate sustainability. The basic objective of the survey was to identify the set of practices adopted by the productive sector to reduce the input of natural products and generate less effluent. The results were surprisingly encouraging. The summary of the 412 entries that comprise the yearbook is extremely positive, since 44% of businesses only hire suppliers who use environmental management procedures, 47 % use renewable energy sources, 49 % research technologies to reduce atmospheric emissions, 53 % possess ISO 14,001, 59 % develop tree planting programs, 61 % have goals to reduce consumption of water and electricity, 81 % stated on the organizational chart, who bears the responsibility for environmental management and 81 % practice selective waste collection.

The following examples show some of the data from the survey, demonstrating the efforts related to, reducing use of natural resources and to environmental protection by the industrial and agricultural sectors, the services sectors and the commercial sectors. Aside from several environmental practices, they list monitoring actions, assurance of legal compliance, investments in treatment technologies, awareness campaigns and target for reuse (use of sewage, industrial effluents and lower quality water treated for beneficial purposes); and for recycling (a particular for of reuse, in which industrial effluents, treated or not, are used directly in the same process, scheme or industrial system). Table 4.1 shows that 66 % of the industrial and agricultural businesses surveyed, develop targets for reducing consumption of water, 55 % for recycling and that only 3 % of them do not practice any sort of action related to reduction of demand. Table 4.2 shows that 48 % of the businesses of these sectors have targets for reuse and 43 % for recycling of industrial effluents. It also shows that a majority of businesses (80 %) have effluent treatment plants and that 59 % are engaged in reducing wastewater generation through investments in treatment technologies.

It is therefore noticeable, that even though the "environmental cost" is quite significant in regards to the global cost of production, the businesses of the industrial and agricultural sectors (especially those linked to agribusiness) consider that the inclusion of policies for environmental management are converted into benefits of gains in quality and in industrial competitiveness (Pio 2008).

The chemical industry, for example, became as of the mid twentieth century, one of the biggest and most globalized sectors of the world economy. Yet, the importance and the diversity of chemical products and their influence in improving the population's quality of life, need to be analyzed in light of their elevated consumption of water and energy and in light of the potential negative impacts on the environment and on public health. In order to overcome this antagonism, the International Conference on Chemical Management—ICCM, which occurred on February 6th, 2006 in Dubai,

Table 4.1 Consumption of water in percentage of businesses per alternative

Actions they consider as practices	Industry and agriculture (%)	Services (%)	Commerce (%)
Monitoring with specific indicators	3	51	67
Recycling	55	17	27
Reduction goal	66	45	73
Structured Program	38	13	33
Employee Awareness Campaign	63	52	47
Do not develop specifications	3	18	13

Response stimulated and multiple (Environmental Management Analysis, Yearbook 2007)

Table 4.2 Treatment of effluents in percentage of businesses per alternative

Actions they consider as practices	Industry and agriculture (%)	Services (%)	Commerce (%)
Monitoring with indicators	79	37	53
Goals for reuse	48	15	20
Goals for recycling	34	8	7
Process for reducing generation	59	23	27
Investment in technology for reducing generation	49	15	27
Process treatment plants	80	40	53
Assurance of legal compliance in management, transportation and destination	77	50	53
Do not develop specific actions	2	24	33
Others	4	10	0

Response stimulated and multiple (Environmental Management Analysis, Yearbook 2007)

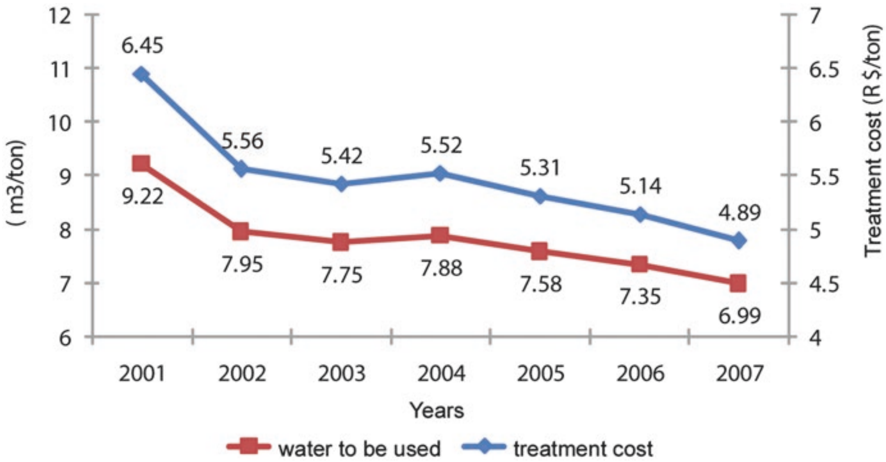

Fig 4.1 National chemical industry: results of the water demand management measures and the corresponding reduction of the treatment costs (Abiquim 2008)

United Arab Emirates, enacted the Strategic Approach to International Chemicals Management—SAICM, which determined the policies for international actions on chemical dangers, specifying that by the year 2020, all chemical products will need to be produced and used in a way to minimize significant negative impacts on the environment and public health.

In terms of environmental protection, particularly concerning conservation and the reuse of water, Brazilian Chemical industries have been adequately responding to the principles established by SAICM (Abiquim 2008). As shown on Fig. 4.1, the chemical industries associated to the Brazilian Association of Chemical Industries—Abiquim, show a reduction in the indicator of water consumption from

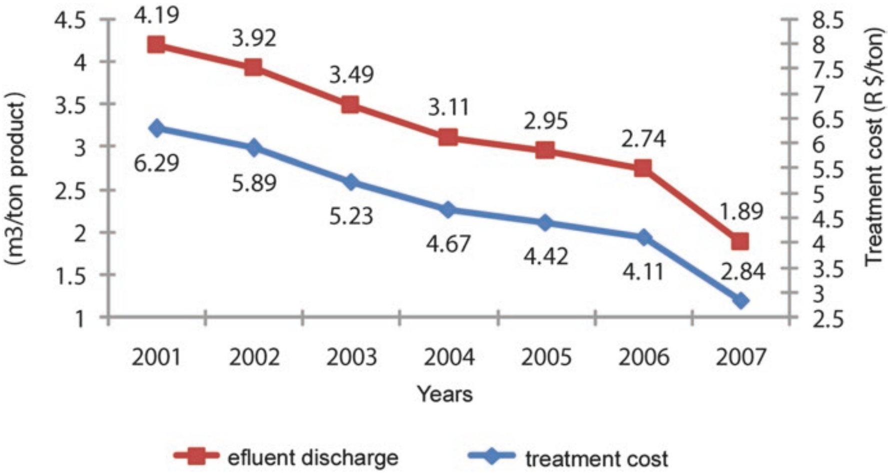

Fig. 4.2 National chemical industry: reduction of the emission of effluents between 2001 and 2007 and the corresponding reduction in treatment costs (Abiquim 2008)

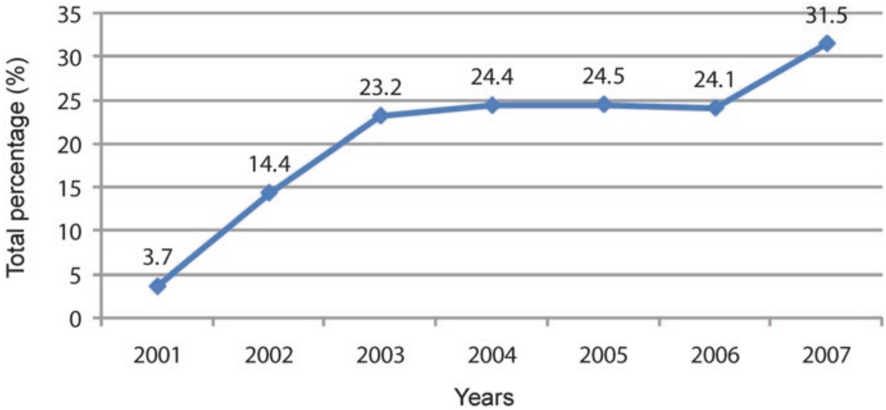

Fig. 4.3 National chemical industry: increase in the percentage of water reuse between 2001 and 2007 (Abiquim 2008)

9.22 cubic meters per ton of manufactured products to 6.99, a reduction equivalent to approximately 24 %. In terms of reduction of emission of effluents, as shown on Fig. 4.2, the indicator varied from 4.19 cubic meters per ton of product to 1.89, a reduction equivalent to approximately 55 %.

These extremely positive variations of the indicators of consumption and emission of effluents most certainly occurred due to the growth of the practice of reuse made by the businesses of the sector. The increase of this practice, during the last 6 years was superior to 88 %, varying from 3.7 % of reuse of the total to 31.5 % as shown in Fig. 4.3.

Opportunities and Constraints for Industrial Sustainability

The text "How Smart Companies Use Environmental Strategy to Innovate, Create Value and Build Competitive Advantage", a sub-title of the book Green to Gold (Esty and Winston 2006) defines, contrary to what some businessmen still consider as a constraint, the most notable opportunity to promote industrial sustainability. The authors devised the term "eco-advantage" to refer to issues and opportunities for the development of business within an environmentally sensitive society. Aside from emphasizing that competent businesses create competitive advantages through strategic management of environmental challenges, it also warns that inadequate environmental decisions can generate problems with public relations, destroy markets and careers and cause the loss of billions. Companies that don't include environmental ideas in their strategic arsenals, run the risk of losing opportunities in markets that are continuously molded by environmental factors.

Another beneficial result of the implementation of correct strategies of environmental management is the fact of obtaining a positive corporate image, or and "eco-image", which can result in superior outcomes compared to those supplied by extensive advertising and marketing programs.

While, currently, there is a strategic vision that one must adapt to the environmental and public health demands required by the market, the industry is subject to two major instruments of pressure. On the one hand, the impositions resulting from international trade relationship, in other words, the environmental and public health standards and certifications that, although might have a unique characteristic of protectionism of markets and products, increasingly demand an environmental and hygienic commitment from production, especially from that which is exported; and on the other hand, the recent legal and economic constraints associated to the management of water resources, particularly those related to the charges for the use of water (Pio 2005).

In order to adapt to the new scenario, the industries have opted to improve their industrial processes and develop environmental management systems that meet the specifications of domestic and foreign markets, and implement systems and procedures aimed at managing water demand and minimizing waste generation.

Options for Promoting Industrial Sustainability in Terms of Water Resources

Depending on the availability of water, in light of emerging technologies, the feasibility of industrial production with regards to water infrastructure is conditioned to the evaluation of the following options, which are not necessarily mutually exclusive: (1) maintain the traditional situation, in other words, use water from the public water distribution system and from surface and underground water resources;

(2) purchase reuse water or water utility from sanitation companies, through further treatment of their secondary effluents; or (3) treat and reuse, as far as possible, their own effluents following adequate treatment (Hespanhol 2008).

Maintain the Traditional Situation

The industry uses variable fractions of natural water, surface or ground water, and water from the public distribution system. Regardless of the source being used, it will need to bear the costs associated to the charges for the use of water and for the release of effluents and, if it uses water from the public network, the costs associated to their corresponding charges as well. In general, surface waters are polluted, and most times will require significant investments in order to achieve adequate levels of quality for their specific uses. When there is local availability, the tendency is to prefer ground water since it is usually of better quality and can be used following relatively simple treatment systems.

The consumption of surface water is being reduced in most parts of the country by the majority of industries. In the state of São Paulo, during the period of 1999–2000, the reduction was of approximately 15 %, as shown on Table 4.3 (DAEE 2000b).

Similarly, the consumption of water of the public distribution system is gradually decreasing. The volumes billed by the Basic Sanitation Company of the State of São Paulo—SABESP (SABESP 2000) showed a decrease in consumption of 40 % in the State of São Paulo, as indicated in Table 4.4.

Although the use of surface water implies in a smaller investment in treatment, the reduction should partly be attributed to the management of demand, implemented by the industrial sector. This also occurs with regards to the consumption of the water of the public systems, although in this case, the basic reason is associated to the elevated costs imposed by the sanitation companies. Table 4.5 shows the industrial tariffs charged by SABESP in most parts of the Metropolitan Region of São Paulo, RMSP, after the price adjustment implemented on September 10th, 2007 (SABESP 2007).

Table 4.3 Variation of surface water consumption by industrial segments in the period 1990–2000 (DAEE 2000b)

Superficial extraction ($m^3\ s^{-1}$)		
Industrial segment	1990	2000
Sugar and alcohol	46,240	42,300
Chemical and petrochemical	17,970	15,900
Pulp and paper	13,200	11,600
Metallurgy	10,640	7000
Food and beverages	10,550	6700
Textile	4190	4000
Total	102,790	87,500

Table 4.4 Volumes of water and sewage billed by SABESP in the period 1998–2000 (SABESP 2000)

Year	Volume of water (10^6 m^3)	Volume of sewage (10^6 m^3)
1998	39.0	25.0
1999	34.0	28.0
2000	33.0	30.0
2001	31.0	27.0
2002	31.0	28.0
2003	30.8	29.2
2004	23.4	23.2

Table 4.5 Industrial costs of water supply and sewage collection services practiced by SABESP for most parts of the RMSP (SABESP 2007)

Supply (m^3 month)	Water rates (R$)	Sewage rates (R$)
0–10	24.94/month	24.94/month
11–20	4.84/m^3	4.84/m^3
21–50	9.31/m^3	9.31/m^3
Above 50	9.69/m^3	9.69/m^3

Purchasing Reuse Water from Sanitation Companies

Although still at a very slow pace, some municipal and state sanitation companies are starting to supply reuse water to meet the needs of a relatively significant range of non-potable urban and industrial uses.

SABESP elaborated through a consultancy company, a project (SABESP 2004) that analyzes the potential for reuse of treated effluents within a radius of approximately 5 km of its main sewage treatment plants (Barueri, ABC, Suzano, São Miguel and Parque Novo Mundo). In each region, they performed a consumer market analysis, current and future estimates on demands for water and a study on willingness to pay (spontaneous value). The total estimated investment is of about R$ 140 million, of which approximately R$ 71 million would be from their own resources and R$ 69 million would be obtained through financing. The economic study was conducted for a period of 25 years, with interest at 15 % per year. The period of return was estimated in 7 year and the internal return rate at 18 %. The market study basically indicated a great potential of meeting the needs of the industrial sector, by using good quality reuse water as replacement water in cooling towers.

The costs per cubic meter of reuse water, based on demand and willingness to pay, are presented in Fig. 4.4. One can notice that the average value or reuse water (R$ 1.58/m^3) is almost the same as the spontaneous value (R$ 1.55/m^3). The proposed billing system is shown on Fig. 4.5. The price, even for the range of lower consumption (up to 10,000 m^3/month), in other words, of R$ 1.89, is quite inferior

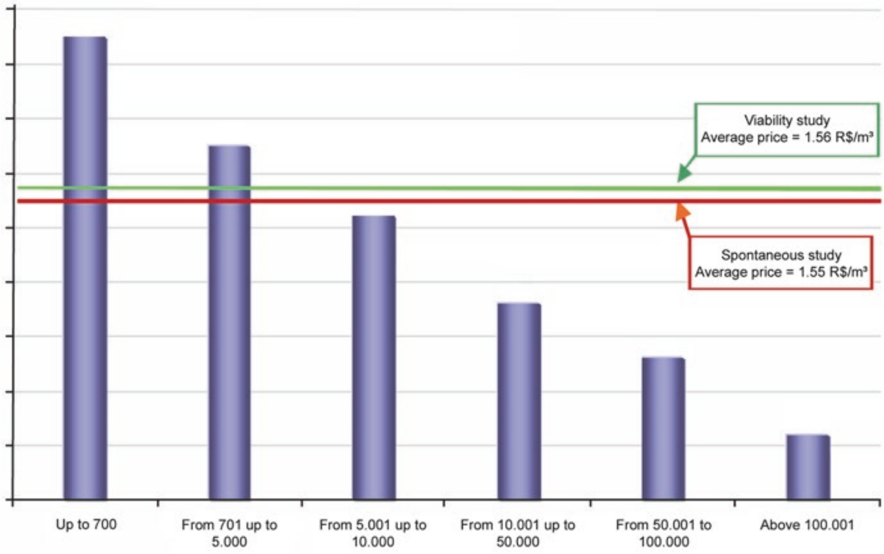

Fig. 4.4 Costs associated with ranges of monthly volumes. The feasibility study defined an average value of R$ 1.58/m^3 and a spontaneous value of R$ 1.55/m^3 (SABESP 2004)

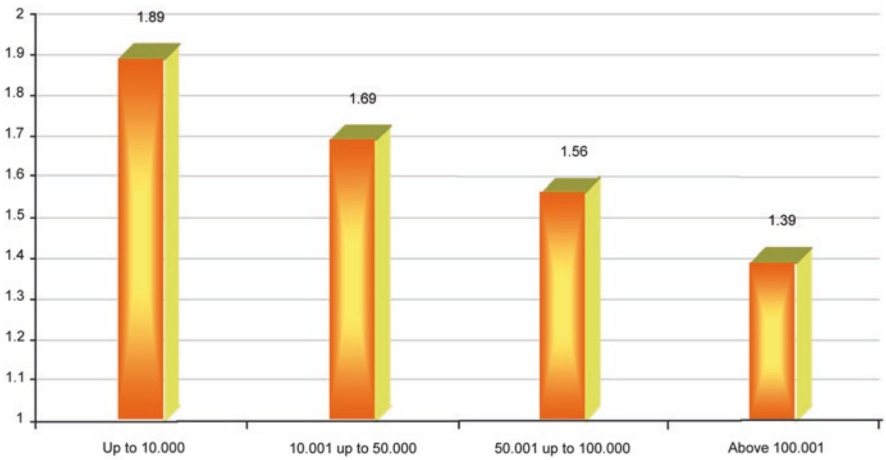

Fig. 4.5 Proposed billing system based on consumption rates (SABESP 2004)

to the prices charged by SABESP for potable water, for any of the consumption ranges. Therefore, it becomes quite evident that the sanitation companies have no interest whatsoever in the practice of reuse, since the process would result in significant loss of revenue. The companies that advertise the sale of their treated effluents say that the reuse market is aimed exclusively at new consumers. This assertion is not compatible to the reality of the market, because all clients will start to demand reuse water where it's available, due to the great differences in the tariffs, as shown.

The practice of reuse, in an ample way, in a way that would generate a significant reduction on the demand of water resources, will only occur through a political-institutional decision and through the enactment of a realistic legal framework that could effectively be implemented by the basin committees.

Treat and Reuse Your Own Effluents

In the area of São Paulo, the billing for the use of water is being done based on Law N° 12.183 of December 29, 2005, which was regulated by Decree N° 50.667 of March 30, 2006. The billing for the use of water, even in basins in which the legislation has not been implemented, it has conditioned the industries, for precaution, to two basic actions: management of demand and reduction of produced effluents, by adopting the practice of reuse.

The Federation of Industries of the State of São Paulo, FIESP, considering the economic effects which can derive from the billing for use of water in the industrial sector, produced a manual, with the technical support of the International Reference Center on Water Reuse—CIRRA/IRCWR and of DCT Engineering, on the conservation and reuse of water in the industry (FIESP/CIESP 2004). Several other manuals contemplating the sectors of sugar and alcohol, petrochemical, steel, paper and pulp, pharmaceutical, etc., will also be developed in the future in order to steer conservation and water reuse practices in specific sectors. Following the steps of FIESP, the Federation of Industries of the State of Rio de Janeiro—FIRJAN, produced the Manual for Conservation and Water Reuse in Industry (Hespanhol and Gonçalves 2006). Similarly, the Union of the Construction Industry of São Paulo, SINDUSCON, elaborated a manual with the technical support of several companies, including CIRRA/IRCWR, on the conservation and water reuse in buildings (SINDUSCON, ANA, FIESP, COMASP 2006).

The methodology to be implemented by industries aiming to reduce the demand on water and aiming at reusing their own effluents, and thus reduce the costs associated to the use of water, is summarized in Fig. 4.6.

The basic steps for a management program in an industry are the following, as shown in Fig. 4.6 are:

Management of Demand

Management of demand aims to reduce the volume of water taken from any source. Since, a little over a decade ago, water was considered an inexpensive, unlimited resource, the industrial sector had no concerns with regards to quantifying the

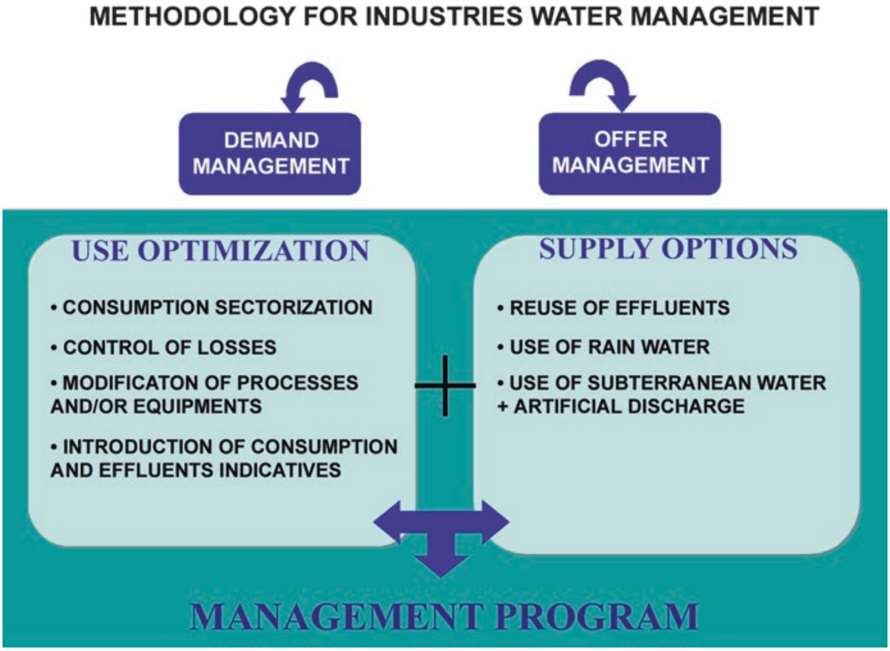

Fig. 4.6 Integrated program of water management in industries through conservation and water reuse practices (FIESP/CIESP 2004)

consumption of water in each of its sectors. Therefore the first part of the management of demand consists in measuring and monitoring the consumption in each sector, in other words, gather and record the consumption of water for specific uses, such as: washing of parts and reactors, industrial processes, domestic consumption, generation of energy, heating or cooling, human consumption, etc.

In addition, the control over the physical losses within the industrial system, such as leakage of water in pipes, connectors, tanks and equipment, the losses associated to the poor performance of the systems and the losses due to negligence of users should be made. A program to detect invisible losses should also be implemented.

The action that may require large capital resources is that which addresses the upgrading of machines, appliances and equipment that compose the production system, including those of instrumentation and control. The objective is to substitute old systems for modern units, which utilize less water and/or generate a smaller volume of effluents. The equipment which are not substituted should also be looked into, to verify the corresponding operational practices with regards to their real need for water, both in terms of quality as well as in terms of quantity.

The establishment of indicators of consumption (m^3 water/unit of product) and of generation of effluents (m^3 effluents/unit of product) constitute important control mechanisms which should be considered by the industries based on available information in Brazil and abroad. The manual produced by FIESP (FIESP/CIESP 2004) presents, in its Annex I, international consumption indexes for the year of 1990 by industrial segment. The majority of these indicators should be adapted to the local conditions for each type of industry and also be adapted with regards to the new technological developments on industrial processes and treatment systems currently available.

Management of Supply

The management of supply is aimed at using alternative sources of water to substitute traditional ones. Many industries use water from the public systems only, considering that the water quality is adequate for its uses. What occurs many times, is that the quality of these waters is actually superior to the quality needed, and could be substituted by water of inferior quality possibly available in the industry itself, with or without additional treatment, at a lower cost.

The options for eliminating or reducing the uptake from traditional sources are:

1. Industrial effluent themselves, which could be used with or without treatment.
2. Rainwater collected from rooftops or eventually from internal paved areas.
3. Ground water, supplemented by managed recharge from underlying aquifers, which eventually exist within the lands of the industry, using adequately treated industrial effluents.

As systematic support to industries in water reuse programs, the International Reference Center on Water Reuse, CIRRA/IRCWR, establishes the following preliminary basic actions, following the management of demand phase: (1) identification and characterization of all the effluents of importance; and (2) identification of the water reuse potential in the industry, with the assessment of qualities and flow rates required, and the locations of areas of use. These two conditions will determine the treatment system that needs to be implemented. These treatment systems should be implemented in a progressive manner, using simpler operations and individual processes to meet the needs of the uses which require water of lower quality, and then progressing to more advanced units as the need for better quality water becomes necessary. Once the "layout" of the entire system has been made, in terms of treatment and distribution of recovered water, mass balances are carried out in order to identify the concentration cycles and then finally, the "pinch" methodology is implemented, which optimizes the reuse system to be used (Mierzwa and Hespanhol 2005a).

Although the experiences available on implementing the conservation and reuse methodology in industries are limited, there are data to estimate that, when there are no significant additional costs for transportation and final disposal of sludge resulting from treatment, the average costs of treated effluents vary between R$ 0.80/m^3 and R$ 1.20/m^3.

Assessment of Viability

Viability of industrial production in the RMSP, with regards to use of water and generation of effluents, can be assessed by looking at the costs and prices shown on items 4.1 and 4.3 above. The industrial water supplied by the public distribution system has a cost that varies between R$ 4.84/m^3 to R$ 9.69/m^3, depending on the monthly consumption (Table 4.5), while the availability water from reuse varies between R$ 1.39/m^3 to R$ 1.89/m^3, also based on monthly demand (Fig. 4.5). Since the costs estimated for treatment and reuse of the effluents produced in industries vary between R$ 0.80/m^3 to R$ 1.20/m^3, it becomes evident that this is the area for which the industries will show the most interest.

The costs for treatment and reuse, within industries, nevertheless, need to take into consideration the following: first, these costs depend on the characteristics of each specific industry, so a viability study considering capital costs involved, repayment period, interest rates, internal rate of return etc., would be necessary for each one of them. Another aspect which needs to be considered is that the costs associated to the treatment of effluents, needed to meet the standards of discharge established in the Resolution CONAMA 357, should not be associated to the costs of reuse. Only the costs related to the additional treatments, needed to meet the levels of qualities superior to the standards of discharge, should be associated to the costs of reuse.

Current State of Industrial Reuse in Brazil and in the State of São Paulo

Industrial reuse, similar to other forms of reuse, has been rapidly spreading throughout Brazil. In the states of Bahia, Ceará, Paraíba and Rio Grande do Norte, some isolated cases have occurred, but a greater concentration can be found in the regions of the South and Southeast of the country. In the Paraíba do Sul basin, where billing for water already occurs, reuse is practiced by approximately 50 % of the large industries, 16 % of the medium sized industries and by 11 % of the small ones. Of the more than 32 million cubic meters of withdrawn water, 25 %, in other words, a little over 8 million cubic meters are reused, mainly by the steel sector (IPEA 2004).

The industries listed in Table 4.6 invested considerable resources in conservation and reuse programs, attaining a reduction in water consumption of 40–80 % (FIESP 2005).

Table 4.6 Large industries with significant investments in conservation and water reuse (FIESP 2005)

Industry	Main activity
3 M of Brazil	Chemical industry
Aegis	Microelectronic industry
Alpargatas Santista Têxtil	Indigo fabric producer
Alsco Toalheiro Brasil	Industrial laundry
AmBev	Production of beverage
AMP do Brasil	Terminals, connectors and connecting systems
Brastemp	Electro domestics
BSH Continental	Stoves unit
BSH Continental	Refrigerating systems unit
Burigotto	Baby strollers and accessories
Cermatex	Textile industry
Coats Corrents	Textile industry
Companhia Brasileira de Bebidas	Beverages production
Continental	Electro domestics production
DaimlerChrysler	Vehicles assemblage
Dow Chemical	Chemical products production
Elekeiroz	Chemical industry
Ferro Enamel do Brasil	Chemical industry
Ford Motor Company	Mechanical industry
Freios Vargas	Break systems for vehicles
INA Brasil	Rolling systems
Janssen Farmacêutica	Pharmaceutical industry
Kodak of Brazil	Photographic industry
Mahle Metal Leve	Metallurgic industry
Maxion Componentes	Metallurgic industry
Natura	Cosmetics industry
Pilkington Brasil	Glass industry
Polo Petroquímico de São Paulo	Petrochemical products
Replan/Revap/Petrobras	Oil refinery
Rhodia	Chemical industry
Rohm and Haas Química	Chemical industry
TRW Automotive	Metallurgic industry
Volkswagen	Vehicle assemblage
Votorantim	Paper and celulose industry

Simulation of the Reduction of Costs Associated to the Billing of Water due to Reuse, in Some Industries of the State of São Paulo

The state of São Paulo has about 130,000 industries. Approximately 8000 of them are large and medium industries, and the rest are classified as micro enterprises.

In order to assess the economic benefits which can result from the practice of reuse, a simulation was made with 2311 industries from São Paulo, evaluated as one as if they operated as a single industry, taking into consideration the billing for the use of water and for the discharge of effluents, in accordance to the current legislation for the state of São Paulo (Mierzwa and Hespanhol 2005b). The number of industries per hydrographic unit, the inflow captured and the effluents discharged are presented in Table 4.7 (DAEE 2000a).

The total inflow captured by the 2311 industries listed is of 112.75 $m^3 s^{-1}$ and the total effluent discharged is of 83.47 $m^3 s^{-1}$. Therefore, the consumption of water of the 2311 industries is of $112.75 - 83.47 = 29.28$ $m^3 s^{-1}$.

The charging for the use of water, in accordance to the current legislation, weighs on the captured inflow, the consumed flow and on the flow of discharged effluents, the latter being associated to the concentrations of Settleable Solids (SS), the Inorganic Load (IL), Biochemical Oxygen Demand (BOD) and the Chemical Oxygen Demand (COD).

Table 4.7 Demand of industrial water in 2311 industries located in the state of São Paulo (DAEE 2000a)

Hydrographic unit	Number of industries	Intake discharge ($m^3 s^{-1}$)				Effluents discharge ($m^3 s^{-1}$)
		Superficial	Subterranean	Net	Total	
Piracicaba	440	13.88	0.33	0.70	14.91	11.17
Tietê/Sorocaba	383	9.60	0.57	0.22	10.39	7.05
Alto Tietê	593	7.67	1.20	1.17	10.04	7.02
Baixo Tietê	37	1.79	0.03	0.02	1.84	1.65
Tietê/Batalha	19	1.39	0.04	0.09	1.52	1.25
Tietê/Jacaré	77	8.49	0.35	0.01	8.85	6.85
Aguapeí	20	0.76	0.03	0.02	0.81	0.60
Peixe/S. Anastácio	63	0.57	0.22	0.06	0.85	0.55
Baixo Paranapanema	56	2.72	0.18	0.01	2.91	2.65
Alto Paranapanema	23	3.48	0.01	0.02	3.51	0.49
Ribeira do Iguape	9	1.33	0.00	0.00	1.33	1.32
Baixada Santista	43	12.97	0.05	0.20	13.22	10.76
Litoral Norte	1	0.00	0.00	0.00	0.00	0.00
Paraíba do Sul	164	7.20	1.13	0.19	8.52	4.51
Mantiqueira	3	0.04	0.00	0.00	0.04	0.01
Alto Pardo/Moji	182	5.38	0.11	0.11	5.66	4.93
Sapucaí/Grande	26	0.02	0.04	0.04	0.10	0.08
Baixo Pardo/Moji	98	24.33	0.51	0.14	24.98	20.11
Pardo/Grande	22	1.38	0.03	0.00	1.41	0.70
S. José dos Dourados	5	0.23	0.00	0.00	0.23	0.20
Turvo/Grande	46	1.45	0.16	0.02	1.63	1.51
Total	2311	104.68	5.05	3.02	112.75	83.47

The calculation of the values to be charged is done with the following equation:

$$C = \text{uptake} + \text{consumption} + \text{dilution of effluents}\left(\text{BOD} + \text{COD} + \text{SS} + \text{IL}\right)$$

Or in its extended format:

$$C = \left(PUF_{CAP} * Q_{CAP}\right) + \left(PUF_{CONS} * Q_{CONS}\right) + \left(PUF_{BOD} * Q_{BOD} + PUF_{COD} * Q_{QOD} + PUF_{SS} * Q_{SS} + PUF_{IIL} * Q_{IL}\right)$$

where:

Q_{CAP} = inflow captured
Q_{CONS} = inflow consumed
Q_{BOD} = flow of discharge associated to BOD
Q_{DQO} = flow of discharge associated to COD
Q_{SS} = flow of discharge associated to SS
Q_{IL} = flow of discharge associated to IL
PUF_{CAP} = final unit price for capture = PUBCAP $x_1, x_2 \ldots x_n$
PUF_{CONS} = final unit price for consumption = PUBCON $x_1, x_2 \ldots x_n$
PUF_{BOD} = final unit price for BOD = PUBBOD $Y_1, Y_2 \ldots Y_n$
PUF_{COD} final unit price for COD = PUBCAP $Y_1, Y_2 \ldots Y_n$
PUF_{SS} = final unit price for SS = PUBCAP $Y_1, Y_2 \ldots Y_n$
PU_{FIL} = final unit price for IL = PUBIL $Y_1, Y_2 \ldots Y_n$
X_i = coefficients multipliers associated to the uptake and surface waters and ground water (purpose of use, receptor class, seasonality, others)
Y_i = coefficients multipliers associated to the discharge, dilution, transport and assimilation of effluents (origin, receptor class, seasonality, others)
PUB = basic prices associated to uptake, consumption, BOD, COD and IL

Simulation was performed for the following characteristics:

Receptor Class 2
Industrial Effluents, with BOD and IL loads only; seasonality regime
Q_{CAP} = 112.75 $m^3\ s^{-1}$ (Table 4.7)
Q_{CON} = 112.75 $m^3\ s^{-1}$ − 83.47 m^3/s = 29.28 $m^3\ s^{-1}$
$Q_{BOD} = Q_{IL}$ = 83.47 $m^3\ s^{-1}$
PUB_{CAP} = R$ 0.03/m^3 (average) resulting in PUF_{CAP} = R$ 0.036/m^3
PUB_{CON} = R$ 0.06/m^3 (average) resulting in PUF_{CON} = R$ 0.072/m^3
PUB_{BOD} = R$ 0.55/kg (average) resulting in PUF_{BOD} = R$ 1.07/kg
PUB_{IL} = R$ 1.00/kg (average) resulting in PUF_{CAP} = R$ 10.00/kg
X_1 = 1.2 (industry); X2 = 1.0 (Class 2); X3 = 1.0 (seasonality)
Y_1 = 1.3 (industry)
Y_1 = 1.5 (Class 2)

The result of the simulation considering 0–60 % of reuse is shown in Table 4.8. The analysis of Table 4.8 shows that if the 2311 industries considered were concentrated into one single industrial unit, the cost for the use of water, without reuse, would be of

Table 4.8 Potential reduction in costs for the use of water due to reuse in the state of São Paulo

Demand ($m^3\ s^{-1}$)	Reuse (% demand)	Effluents generation ($m^3\ s^{-1}$)	BD (kg m^3)	Payment income (R$ day^{-1})	Total charge (R$ day^{-1})
112.75	0	83.47	0.060	462,998.10	995,840.70
	10	72.20		400,484.70	898,273.10
	20	60.92		337,915.90	800,619.00
	30	49.64		275,347.10	702,996.00
	40	38.37		212,833.80	605,397.40
	50	27.09		150,265.00	507,774.35
	60	15.82		87,751.64	410,175.64

approximately R$ 1 million a day. By reusing approximately 60 %, a perfectly doable percentage in the majority of the industries, the cost would be reduced by approximately R$ 400 thousand per day.

Conclusions and Recommendations

In the industrial sector, the achievement of the much desired sustainable entrepreneurship depends upon the level, in which the conservation of natural resources is done, particularly of the water resource, mainly through the implementation of environmental management concepts, through eco-efficiency of the productive process and through the use of clean production practices.

Aside from theses internal characteristics, several other exogenous restrictions limit sustainability of the industrial sector, both with regards to the economic aspects as well as those associated to the availability of infrastructure for an adequate production. These issues, which appeared mainly at the end of the last century are constraints imposed by the international markets and legal and economic restrictions worldwide.

However, in light of the new issues and concepts which promote the role of the industries through the implementation of clean management practices, the industrial sector has shown, in the last decades, that the challenge of producing and at the same time consciously using the natural resources, is being met in a satisfactory way through the use of new technologies and through the adequate implementation of modern concepts of environmental management.

The modern concept of industrial entrepreneurship does not consider the investments in environmental management, as detrimental to the company's financial balance, and yes as positive elements, with potential to attribute value and safety to their assets and to promote a greater return to investors. Another beneficial result deriving from the implementation of correct strategies of environmental management is the positive image, or the "eco-image" that is created, which brings superior returns to those supplied by extensive programs of advertising and marketing.

Depending on the availability of water and due to emerging technologies, the viability of industrial production is subject to the analysis of the following options, which are not necessarily mutually exclusive: (1) maintain the traditional situation, in other words, use water from the public water distribution system and from surface and underground water resources; (2) purchase reuse water or water utility from sanitation companies, through further treatment of their secondary effluents; or (3) treat and reuse, as far as possible, their own effluents following adequate treatment.

The quantitative analysis of these options allows us to conclude that internal reuse, practiced within the industries themselves, leads to a unit cost of water inferior to those associated to collection and treatment of surface water, and to the charges practiced by sanitation companies, both with regards to the costs related to public water supply systems as well as those of reused water distribution.

Industrial reuse is rapidly spreading throughout Brazil. It's practice is associated to environmental, social and economic benefits, and constitutes, within the current water billing system, a factor of extreme importance for industrial sustainability.

However, the universalization of the practice of water reuse in Brazil, in light of the significant income loss of the sanitation companies who could implement it in a large scale, is far from happening. The ample implementation of water reuse, to the extent of significantly reducing the demand on water resources will only occur through a political—institutional decision and through the enactment of a realistic legislation, which can be effectively implemented through watershed committees.

In view of the fact that relatively little has been developed in Brazil, there are still ample possibilities for the performance of businesses with regards to the implementation of adequate environmental management. It is probable that in the near future, new social, environmental, public health and legal demands, lead to a critical situation in terms of investments within the sector, forcing the corporate market to establish a balance between what can be earned and investments in management. One of these demands, which will probably occur very soon, will be the statutory requirement for industries to include in their balance sheets, their environmental liabilities, accumulated over years of operation.

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Chapter 5
The Issue of Water in the Brazilian Semi-Arid Region

José Almir Cirilo, Suzana M.G.L. Montenegro, and José Nilson B. Campos

Abstract Soil, climate conditions and socio-economic characteristics in the Brazilian semi-arid region require specific technologies aiming at water resources use and conservation. In addition to the water scarcity condition, incorrect use of water resources in the region enhances the susceptibility to desertification. Impacts of possible climate change may also negatively interfere in the productive processes, health conditions, quality of life and water availability. In this context, non-convention and low cost technologies, with easy assimilation by the communities, must be an approach deal to water scarcity problem and supply diffused population. In the present paper, some of these alternative technologies and the importance for the river basin region integration and water transport across long distances are discussed, highlighting the role of water resources management aiming at conservation and sustainable use.

Keywords Semi-arid regions • Water resources conservation • Water resources management

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Introduction

The availability and the uses of water in the Northeast region of Brazil, particularly in the semiarid region, are still a crucial issue with regards to its development. It's true that considerable efforts are being made with the objective of implementing infrastructure capable of providing sufficient water for human and animal supply, and enable irrigation. Yet, these efforts, in a global sense, are still insufficient to resolve the problems which result from the scarcity of water, leaving populations vulnerable to droughts, especially with regards to the diffuse use of water in the rural area.

Anyhow, the expansion and the strengthening of the water infrastructure, with an adequate management, are essential tools to solve the problem, serving as a basic element to minimize rural exodus and promote internal development. In addition to reforms, the last decade of the last century also brought a new paradigm to the country: the need for water resource management. In fact, is was at this time, with the support of the Union and of Law number 9433/1997, the so-called Law of Waters, that the states implemented a new philosophy: to control use by means of instruments such as concessions, and to, still incipient, charge for the use of raw water; make water resource plans for the watersheds and the states; structure management entities and basin organizations; and elaborate programs for structuring reforms. One can even state that, due to historical difficulties, the greatest advances in the management of water resources, in comparison to other regions of the country, have been occurring in the Northeast.

Physical Characteristics of the Semi-Arid Northeast

The Northeast of Brazil is located between the latitudes 1°S and 18°30′S and the longitudes 34°30′W and 40°20′W and occupies an area of 1,219,000 km^2, equivalent to approximately one fifth of the Brazilian territory. The region encompasses the states of Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe and Bahia, where 18.5 million people live, of which 8.6 million are in the rural area (Cirilo et al. 2007).

The climate of the semiarid portion is characterized by a regime of rainfall heavily concentrated in 4 months (February-May) and a large interannual variability. The strong droughts which plague the region have always molded the behavior of the population and were prevalent for the formulation of regional public policies.

The so-called Drought Polygon was created by Law number 175, of January 1936, as an area to be the object of policies to combat droughts. The Polygon was subject to several modifications, having even been inserted into the Federal Constitution of 1946. Currently the Polygon was substituted by the Semiarid Region of the Constitutional Fund for Financing of the Northeast (MMA 2004). The Ministry of National Integration redefined the limits of the semiarid region of the Northeast.

Regional Water Potentials: Surface Waters

The semiarid Northeast is a region low in volume of runoff water from rivers. This situation can be explained due to the temporal variability of rainfall and the dominant geological characteristics, where there is a predominance of shallow soils capping on crystalline rocks and consequently low water exchange between the river and the surrounding soil. The result is the existence of a dense network of intermittent rivers, with few perennial rivers with a strong focus on the São Francisco and Parnaíba Rivers. The rivers within the intermittent regime are found in the northeastern portion which runs from Ceará up until the north part of Bahia. Among these, one of the most important rivers is the Jaguaribe, in Ceará, for its extension and for its potential for use: some of the biggest reservoirs of the Northeast, such as Castanhão and Orós are found within its watersheds.

Surface water potential is represented by the long-term average flow in a section of the river. It is an important indicator since it allows for a first assessment of the lack or abundance of water resources in a spatialized way in any given region.

Figure 5.1 shows surface water potentials expressed by unit of area (shown in liters per second by square meter) in the different watersheds of the region. This is

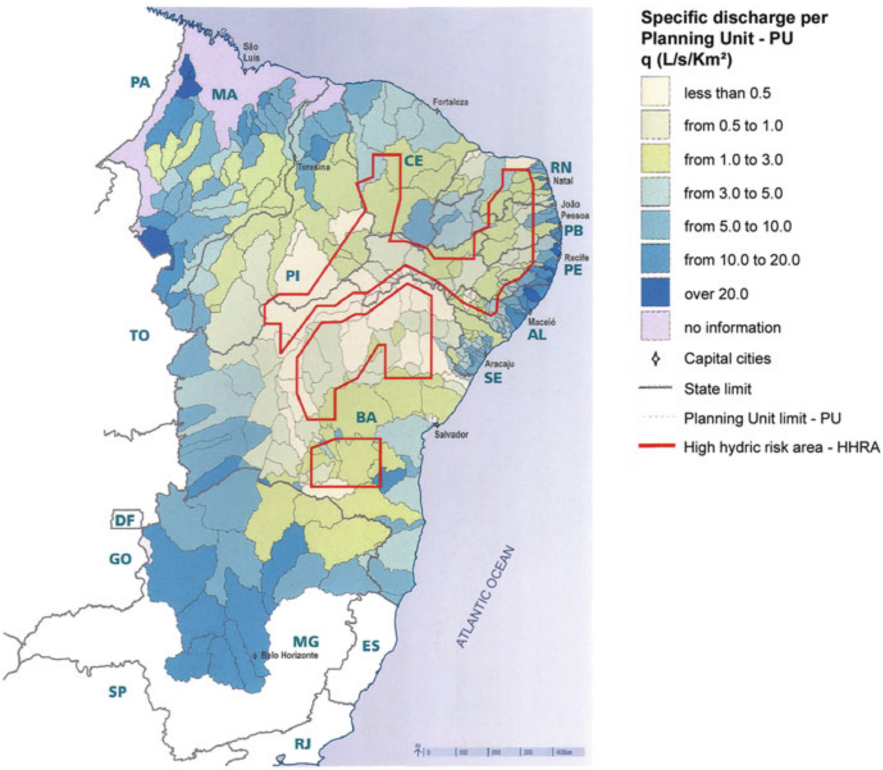

Fig. 5.1 Specific average flows of hydrographic basins of the Northeast of Brazil (From ANA 2005)

the result of hydrological studies performed for ANA/MMA's publication called "Northeast Atlas: urban water supply" (ANA 2005).

Regional Water Potencials: Ground Waters

With regards to the occurrence of ground water, since more than 80 % of the northeastern territory is composed of crystalline rocks, there is a predominance of water with high content of salts captured in wells with low flow rates: about 1 $m^3 h^{-1}$. An exception occurs in the sedimentary formations, where the waters are usually of better quality and higher flow rates can be extracted, of about tens to hundreds of $m^3 h^{-1}$, continuously (Cirilo 2008). Figure 5.2 shows of scheme of the occurrence of aquifers in the Northeast.

Rebouças (1997) highlighted, based on previous studies, that the underground water reserves of the sedimentary basins of the Northeast allows for an annual abstraction of 20 billion of m^3 per year, without endangering the existing reserves, This volume is equivalent to 60 % of the capacity of the Sobradinho reserve in Bahia (34 billion of m^3), primary responsible for regulating the flow of the São Francisco River; of three times the capacity of the Castanhão Dam (6.7 billion of m^3). It is therefore a considerable volume of water. According to Cirilo (2008), it is however necessary to highlight the peculiarities of these reserves, which are:

1. Spatial concentration (with regards to the semi-arid, Piauí and Bahia hold the main aquifers. In the rest of the region, occurrences are sparse sedimentary formations).
2. In several aquifers, due to depth, the cost of implementation and operation of wells become more expensive (Chapada do Araripe, municipality of Bodocó, on the Pernambuco side, there is a 950 m deep well with a capacity of 140 $m^3 h^{-1}$, where the dynamic level of the water is at more than 300 m below the surface of the soil).
3. There is much uncertainly with regards to the recharge mechanisms of sedimentary aquifer of the semi-arid, as well as with regards to the dimension of these recharges; therefore an intensive exploitation can endanger these sources.

For the reasons mentioned above, Cirilo (2008) stated that the underground waters in the sedimentary reserves of the northeastern semi-arid should be used criteriously, preferable for human supply (several cities of the Northeast, located above or close to the sedimentary watersheds are supplied by these sources) and that it makes no sense to consider that this potentiality is capable of meeting regional demands, especially because it would require large transfers of water in order to do this.

Public Health

The incidence of waterborne diseases associated to the poor quality of water consumed by a significant part of the population, especially by those who reside in rural areas, and the precariousness or inexistence of sewage treatment structures, is

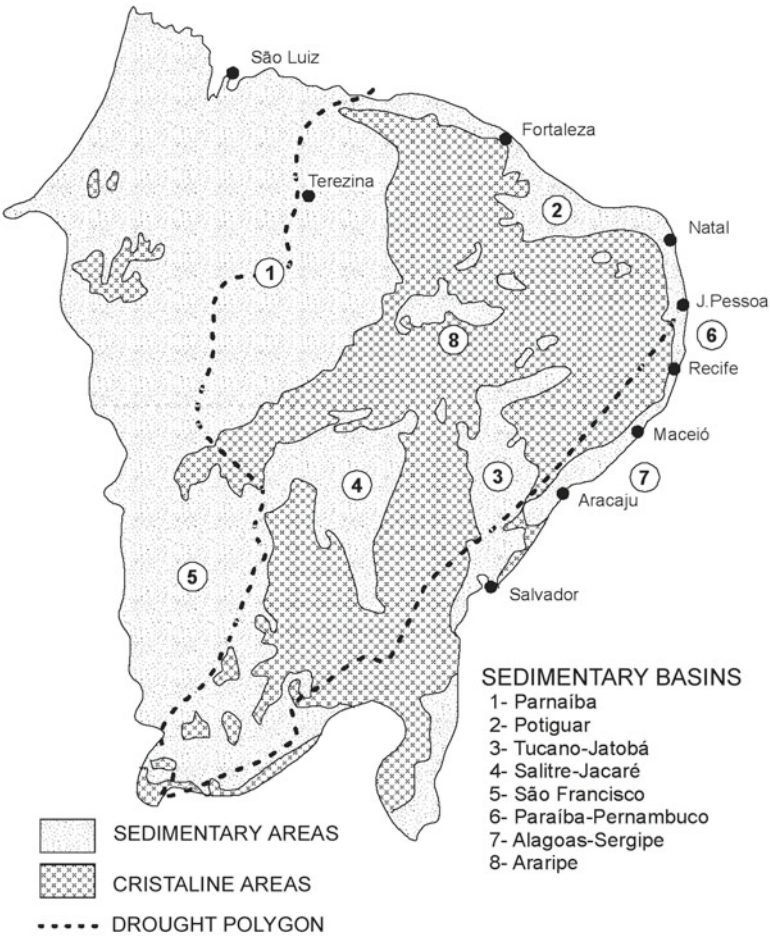

Fig. 5.2 Distribution of sedimentary and crystalline rocks in the area of the Drought Polygon of SUDENE (From Demetrio et al. 2007)

evident, especially in the indicators of infant mortality rates of the region. Costa (2009) developed a research in which he associates the significant decrease in diseases, such as diarrhea, in the infant population of the rural areas of Pernambuco, following the implementation of regular supply systems of water, or even simplified systems of water treatment.

Occurrence of Desertification Process in the Northeast

The United Nation Convention to Combat Desertification defined desertification as the degradation of land in arid, semi-arid and dry sub-humid regions, due to anthropogenic factors and climate change. This degradation is the loss or reduction of economic or biological productivity of the dry ecosystems caused by soil erosion, deterioration of water resources and loss of natural vegetation.

According to a study of the Ministry of the Environment (BRASIL 2002), the areas of the Northeast with severe cases of degradation, the so called "Centers of Desertification", are Gilbués in Piauí, Irauçuba in Ceará, Seridó on the border between the states of Paraíba and Rio Grande do Norte and Cabrobó, in Pernambuco. It is estimated that the desertification process due to diffuse and concentrated impacts on the land of the region has been compromising an area of 181,000 km^2.

The overexploitation of the natural resources in this region have medium-term effects over the quality of the environmental of the region, where there is a predominance of economic activities of farming livelihood, extensive cattle ranching and some perimeters of irrigate agriculture. Several irrigated areas show signs of salinization due to the deficiency or absence of soil drainage. In approximately 600 thousand irrigated hectares of the Northeast, there are signs of salinization and/or of soil compaction in about 30 % of the area (MMA 2002).

Potential Impacts of Climatic Changes

IPCC's report Intergovernmental Panel on Climate Change, called IPCC AR4 (available at http://ipcc-wg1.ucar.edu/) on climatic changes, concluded with over 90 % of certainty that the global warming of the last 50 years is caused by human activity. According to Marengo (2007), the results of this study for South America indicate that the most intense climate changes for the twenty-first century, regarding the current climate, will occur in the tropical region, specifically in Amazonia and in the Northeast of Brazil. These two regions in Brazil are therefore the most vulnerable to climatic changes.

In a warmer atmosphere, one generally expects a more intense occurrence of rainfall in the more humid areas, aside from more frequent dry spells and heat waves. In the semi-arid region, the majority of the scenarios of climate change, indicate, with the increase of temperature: the increase of evaporation in the bodies of water and, consequently, the reduction of the runoff volume from them; the reduction of recharge of aquifers of up to 70 % by the year of 2050 and, therefore, of the feedback of river flows; the concentration of rainy spells in an even smaller frame of time, with a reduction of rainfall (pessimist scenario: for an increase in temperature of 2–4 °C, 15–20 % less rainfall; optimist scenario 1–3 °C warmer, 10–15 % reduction in rainfall); the tendency to increase aridity in the region, with the substitution of the caatinga for more typical vegetation of the arid regions, such as cacti.

Alterations to the hydrological processes in the semi-arid region can result in different types of losses for the communities that live in those regions. As an example, it is probable that an increase of the salinization of surface and ground water would occur due to the increase in evapotranspiration (Bates et al. 2008). In addition, the consequences to changes in the flow regime of the watersheds in these regions can result in losses to the generation of hydroelectric power and for maintaining irrigation projects and the population's water supply. Hydrological studies need to be made in order to predict and assess the consequences of the changes to the flow regime and to hydrological processes in the watersheds of the Northeastern semi-arid. Pinto and Assad (2008) highlighted that in most parts of Brazil the increase of evapotranspiration, with its consequent water stress of the soil, will result in an increase of climatic risks for agricultural productivity. Based on IPCC scenarios and on simulations of scenarios with the future conditions for the cultivation of different crops, the above mentioned authors highlighted that the increase of temperature shall decrease the number of municipalities with agricultural potential in 2020, 2050, and 2070. In addition, according to the authors, with IPCC's estimate of aridification of the Brazilian semi-arid and with the loss of productivity of several crops, there will be consequences with regards to food security in the region.

Solutions for the Problem of Water in the Northeastern Semi-Arid

The Droughts and Their Consequences

Since the early days, droughts have marked the history of the Northeast. Fernão Cardin (cited by Souza 1997) reports that there was a great drought and sterility in the province (Pernambuco) and about four to five thousand Indians descended from the hinterland joining the whites on the coast. It is also worth highlighting Professor João de Deus' citation (Paulino 1992) who reports on movements of the Tabajaras and Kariris besieged by the droughts. It appears from these narratives that migratory movements from the hinterland occurred even at a time of low population density.

The occupation of the hinterland was delayed mainly because of the droughts. Nevertheless, following a royal charter, cattle breeders had to enter the hinterland. From 1845 to 1876, there was a period of 32 years without intense droughts, which resulted in an increase in populations and herds without any increase in the infrastructure of water resources. Then from 1877 to 1879 there was an intense and long drought which resulted in tragic mortality in the region estimated in about 500,000 deaths. It was as of this shock which hit the Brazilian society, that the search for structural solutions (Campos and Studart 1997). It was during this drought that the phrase: "I will sell the last stone in my crown before I let a Northeastern die of hunger", was attributed to Dom Pedro II.

Anyhow, it was as of this tragedy that more effective actions, though still at a slow pace, began to occur. The Cedro Dam in Ceará, which is today a historical monument with low hydrological capacity, was initiated at the time of the Empire.

The Search for Solutions

Confronting the problem of quality water scarcity in the semi-arid did not occur through a single unique solution. The implementation of isolated or combined hydraulic infrastructures constitute the necessary actions to mitigate the problem of water in the semi-arid. To define the adequate infrastructure and the action or management strategy, one should seek to increase availability by increasing the efficiency of how water is used and control demand and waste, notably with regards to irrigation.

Infrastructures can be grouped in order to meet the needs of two types of demands: the concentrate demand and the diffuse rural demand. With regards to the first one, for example, in cities and irrigation perimeters, large flows are supplied and distributed among users who are close to one another. In diffuse rural demand, there is a very large special dispersion and the solutions as specific. Let's begin with the regional problems associated to climate in order to contextualize the practiced and proposed solutions.

Well Drillings

In the Northeast, it is estimated that approximately 100,000 wells have been drilled. Due to the fact that most of the Northeastern semi-arid region is crystalline formation, wells used as solutions for supplying water for the different needs are subject to the following limitations:

1. Low flows, in most cases up to 2 m^3 h^{-1}.
2. Salt content, in most parts of the wells, at significantly superior levels than those recommended for human consumption.

High Rate of Dry Wells, Given the Geological Peculiarities

Wells drilled in crystalline have a depth of about 50 m whereas in the sedimentary basins depths vary from 100 to 300 m.

The drilling of wells in crystalline soils has been done in conjunction with desalination of reverse osmosis for the rural demand. In sedimentary areas, it has been used to meet or supplement the demands of the cities.

Notwithstanding the desalination prove effective in improving the water potability, problems need to be managed, as follows: destination for disposal of waste from desalination, high maintenance cost and complex operational logistics. For the disposal of waste, some solutions have been put into practice, such as: use of tanks with thin blades to increase the speed of evaporation and consequently resulting in the disposition of salts; accumulation in tanks for the farming of fish such as tilapia and shrimp; growing of *Atriplex nummularia*, a plant with high capacity of salt absorption, from Australia and used successfully in Chile, being an excellent forage, which contains about 16–20 % proteins and lives up to 20 years (Montenegro and Montenegro 2004; Porto et al. 2006).

Rural Tanks

The building of cisterns to keep rainwater is natural and intuitive, and has therefore been done for millions of years. There are records of cisterns of more than two thousand years in regions like China and the Negev desert, which today belongs to Israel and Jordania (Gnadlinger 2000).

The cisterns with an accumulation capacity of between 7 and 15 m^3 represent the availability of 50 L of water per day during 140–300 days, that is, if they are full at the end of the rainy season and no recharge occurred during the period. If one takes the necessary care with regards to cleaning the roof, the cistern, the gutters and the pipes, this is an essential solution for meeting the most essential needs of the diffuse rural population. Although there are millions of cisterns spread out in the Northeast, the quantity is still tiny in comparison to the needs of the diffuse rural population.

However, one must bear in mind that in the semi-arid climate, cisterns alone cannot provide sustainability to the people. It should be used as part of the solution for diffuse populations. One example of this limitation can be seen in the Jesuits installations in Dom Maurício, in the city of Quixadá. The Jesuits settled in the area at the end of the eighteenth century and built a convent/school with a water sustainability system based on big cisterns. In the drought of 1915, they closed the convent/school because of an absolute lack of water. Currently the convent is administered by nuns who use the cisterns in conjunction to other sources of water, such as a small dam located nearby.

Ground Water Dams

Underground dams are justifiable based on the need to increase the accumulation of waters in the alluvial aquifers of the intermittent rivers. The rainfall regime, with rain in general lasting a short period of time, yet being of elevated intensity and the limited infiltration capacity of the soil results in much of the rainfall being lost due to rapid surface runoffs. Common devices to capture surface runoff in these watersheds are dams and percolation pits, that due to the elevated rate of evaporation, typical of the semi-arid region, results in much of the stored volume being lost prior to being used. Evaporation also tends to, in these cases, increase salinity in the water captured in these devices, making its use improper for several purposes. Underground dams promote infiltration and storage or rainwater in alluvial deposits, with greater protection from evaporation and salinization, when compared to dams and percolation pits (Costa et al. 2000). Even though it is quite an old and of simple implementation technology, it was not being used in Brazil as a type of water structuring system. Several states of the Northeast have been building underground percolation pits, like Pernambuco, Paraíba and Bahia.

Treatment and Reuse of Wastewaters

In general, the destination of sewage with low or no treatment continues to be the bodies of waters. The consequences of this are: pollution, waterborne diseases, destruction of biodiversity and reduction of availability of drinking water. The disposition of nutrients, especially nitrogen and phosphorous into rivers and reservoirs has resulted in the eutrophication of water sources and in the blooming of toxic algae called cyanobacteria, that constitutes a true plague for the reservoirs. These algae release toxins (neurotoxins e hepatotoxins) which can cause serious damages to human health, and even death. The treatment for contaminated water is not only very difficult but also very expensive.

In the Northeast, reuse of water for industrial activities has been occurring in sectors such as the clothing manufacturing. It is still very limited, being practically exclusive to pilot projects and to the reuse of sanitary effluents, treated or not, for agricultural activities.

One of the aggravating factors of this problem is the construction of water distribution systems without a proper destination for used water. The small reservoirs are particularly vulnerable to this problem. Intermittency of rivers drastically limits their power to self-purify. This is an issue where there is still ample room for research.

Campello Netto et al. (2007) mentioned that in certain countries, like Israel, cultural motives and water deficit favor the disposal of residues into the soil rather than into bodies of water. The application of organic residues in agriculture has been gaining attention due to costs and due to environmental problems associated to the disposal of residues, aside from, as mentioned, the low availability of clean water for the production processes. In the Northeast semi-arid, reuse of water for industrial activities is beginning, in sectors such as the manufacturing of clothing. Hespanhol (2003) highlighted that, in the condition of water scarcity of the semi-arid Northeast, one can emphasize reuse and conservation, as key words in terms of management; the author analyzed water reuse potential in Brazil for several purposes, particularly for those other than drinking. The reuse of sanitary effluents, weather treated or not, is still at its stating point and is mainly being used in pilot projects within the agricultural activities.

Long Distance Water Transportation

With regards to human supply of water in cities of the semi-arid which do not possess a water source nearby, the construction of pipelines is the most adequate solution, regardless of whether they are from great reservoirs or from wells in sedimentary areas (with a greater restriction so that the potentials of these reserves, especially with regards to their recharge mechanisms, can be identified), or even from further away rivers and reservoirs, even in other watersheds, configuring the so called transpositions or water transfers among basins.

Great water adductions were built or are being built or designed to supply the cities of the semi-arid.

For example, the Integration Channel, in Ceará, in its final phase, shall transport water from the Jaguaribe basin for 225 km, starting from the Castanhão reservoir up until Fortaleza. From there the water will be distributed to the entire Metropolitan Region of Fortaleza, including the area of Porto de Pecém.

Another situation which is occurring now is the start of the project for the transposition of waters of the São Francisco River (BRASIL 2000) to the states of Ceará, Rio Grande do Norte, Paraíba and Pernambuco. According to the Ministry of National Integration, by the end of the project, there will be a continuous water withdrawal of 26.4 $m^3 s^{-1}$, equivalent to 1.4 % of the flow supplied by the Sobradinho Dam (1850 $m^3 s^{-1}$). This flow will be destined to the urban population consumption of 390 cities of the Wasteland and Hinterland of the four northern states of the Northeast. In the years in which the Sobradinho reservoir pours, the adduced flow will be able to reach 127 $m^3 s^{-1}$.

The so called North Axis of the transposition was designed for a maximum capacity of 99 $m^3 s^{-1}$ and will operate with a continuous flow of 16.4 $m^3 s^{-1}$, destined for human consumption. The exceeding volumes transferred will be stored in existing reservoirs in the receiving basins. In the state of Pernambuco, the North and East Axis will serve, as they cross their territory, as a water source for the existing adduction systems or in projects which are responsible for the water supply for the populations of the Wasteland and the Hinterland.

Conclusions

The strengthening of the water infrastructure of the Northeast as a policy for coping with drought has been going on since the beginning of last century. Yet there is still a lot to be done. There is also the need to make more efficient investments. There still is, however, a great segment of the rural population who live in vulnerable conditions and with low access to good quality water.

In order to elaborate a good policy, it is important that one understands the particularities of the solutions. One cannot imagine that great channels and pipelines will supply the diffuse rural populations, except for those located near the routes of the projects. Therefore, cisterns, small reservoirs, wells, and desalinization should have their uses improved and increased, particularly with regards to their operation and maintenance. Small dams and underground percolation pits should, where appropriate, be used to promote family farming, in a seasonal way. Fish farming in the big reservoirs is an important source of food and income, as long as limits are respected in order to avoid their eutrophication.

With the use of water resource management, fostered by Law number 9433, emergency actions need to be substituted by planning actions and water management in an integrated, participatory and decentralized way, supporting local, state and non-governmental management agencies. In essence, what we all want for Brazil is a fair, developed and environmentally correct country. Nevertheless, a partially developed country is an underdeveloped country. Thus, the continuation of public policies to reduce regional inequalities is still a task for politicians and governments. To seek the correct understanding of processes and regional policies is the contribution which researchers and scientists can supply.

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Chapter 6
Amazonia: Water Resources and Sustainability

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Abstract Water resources in Amazonia affect all natural and human-altered ecosystems in the region, including their human populations. Evapotranspiration by the Amazon forest provides water vapor that is transported by wind to other regions of Brazil and to neighboring countries. The enormous quantities of water involved in hydrological processes in Amazonia give great importance to the region's water resources and to potential impacts if these cycles are altered. The diversity of fish and other aquatic organisms is enormous, as is the importance of this fauna as economic and food resources for the human population. There are impacts from pollution, including mercury methylation in hydroelectric reservoirs. Dams also block migration of fish and alter the flooding cycles of rivers. Hydroelectric dams release methane, thereby contributing to global warming. The chemical characteristics of different types of water affect processes such as the transport of organic carbon, the supply of nutrients to the plankton that are the base of the food chain in aquatic ecosystems, and the quantity of bio-available ions that affect sensitivity of organisms to copper and other toxic elements. Several of the major rivers in the region drain more than one country, as is the case for the Madeira River, whose basin drains parts of Bolivia and Peru, in addition to Brazil. International treaties require protecting the rights of other countries that share aquatic resources in trans-border watersheds. The hydroelectric dams under construction in Brazil on the Madeira River imply a variety of impacts in the neighboring countries, including blocking the migration of large catfish. One of

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the priorities for rational decision making on aquatic resources in Amazonia is expansion of scientific knowledge on aquatic systems in the region. A series of national and international projects are engaged in improving this knowledge, and masters and PhD programs are increasing the capacity for research in the area. The human population in the region depends on the functioning of aquatic ecosystems. People share the fate of these ecosystems, in which they constitute a central component.

Keywords Biodiversity • Dam • Development • Environmental impact • Fish • Global warming • Hydrological cycle • Hydroelectric dam • Reservoir • River • Water

Characterization and Extent of Water

Only 3 % of the existing water in the world is running fresh water and of this, one fifth is due to the Amazon River's discharge into the ocean. The hydrographic basin of Amazonas is the most extensive hydrographic network in the world, spreading through all the countries in Northern Latin America, ranging from the Andean foothills all the way to the Atlantic Ocean (Eva and Huber 2005). Navigable rivers total 25,000 km. The basin covers about 7 million km^2, of which 3.8 million are in Brazil (IBGE 2007). This continental basin extends through all of the northern South America, with the Brazilian portion representing 63 %. This raises a number of transnational issues in the social, economic, biodiversity and environmental areas, among others, which require a plural analysis of the normative space and of the cultural diversity of the region. The issue of scale has had and still has profound implications for the regional planning processes, and it is not on rare occasions that it is totally neglected.

The Amazon River discharges into the Atlantic Ocean 175,000 m^3 of fresh water per second, which represents 20 % of all the fresh water entering the oceans in the entire world. The encounter of this huge volume of water with the ocean results in a very loud noise, called the "pororoca" (from the Tupi language, meaning "big bang") (reviewed by Val et al. 2006). This water volume results from the contribution of a multitude of small bodies of water that are interconnected inside the forest, and have an important role in the water cycle of the Amazonian region and of the adjacent regions. This discharge is equivalent to five times that of the Congo River (Africa) and 12 times that of the Mississippi River (United States of America). The water bodies of all forms and origins create a unique topographic plan with an extensive set of transition areas between the aquatic environment and solid soil, which (Sioli 1984) called the "aquatic landscape". More than 20 % of the Amazon region can be considered to be wetlands (Junk 2000).

Amazonian wetlands associated with the great rivers are defined as environments that periodically receive lateral inflows of water from these rivers due to annual variations in water levels. These areas cover 6 % of Brazilian Amazonia, or about 300,000 km^2, and they are classified in accordance with their fertility as várzeas (4 %) and igapós (2 %). The várzeas are areas with higher fertility and are inhabited by 90 % of the rural population of Amazonia (Junk 2000). The igapós are, in contrast, low in inorganic nutrients, rich in dissolved organic material, and their waters are extremely acid and clear, or more frequently black, in color (Sioli 1975; Furch 2000).

Environmental diversity in Amazonia is increased by the different types of water, such as the black water of the Negro River, the white water of the Amazon River and the clear water of the Tapajós River. In addition, from a biological point of view, the connection with the Orinoco Basin also has a relevant role. The Cassiquiare Channel in the upper part of the Negro River makes this connection. The main tributaries of the Orinoco River, originate in the Andes, and also bring from there, significant quantities of sediments. However, an even greater quantity of sediments, about 1.2×109 t, is transported annually by the Amazon River to the Atlantic coast (reviewed by Lara et al. 1997), where an extensive interface zone is located.

The difference in density and the volume of water cause the freshwater to move above the salt water for hundreds of kilometers, transporting the sediment directly into the Atlantic Ocean instead of depositing it as it enters the estuary. Circulation in this coastal zone is influenced by strong local currents. Approximately half of the sediments are accumulated along the coast while the other half is spread in the ocean. Thus, this interface zone, which is the largest in the world, is strongly influenced by the dynamics, of the Amazon River, with its maximum flow at the end of May and its minimum in November.

Quality and Monitoring of Water Systems

Aside from their color, waters from Amazonia also have significant chemical, physical and biological differences, which are also strongly related to their drainage areas. In fact, the muddy waters of the Solimões-Amazon system have pH close to neutral, a large quantity of suspended material originating from the Andes and from the land near the edges of the rivers, low levels of dissolved organic carbon and levels of nutrients that are relatively higher than those found in other types of water in the region. In contrast, the black waters are acid, with pH between 3.2 and 5, rich in dissolved organic carbon, particularly in humic and fulvic acids, and are severely lacking in ions, with concentrations similar to those in distilled water. In addition, water in Amazonia often undergoes episodes of low oxygen availability (Furch 1984; Val et al. 2006). The existence of a rich ichthyofauna in these environments is possible thanks to an unparalleled diversity of morphological, biochemical and physiological adjustments in order to maintain ionic homeostasis, as well as ensuring the transfer of oxygen to the tissues (Val and Almeida-Val 1995). This set of biological characteristics can be used to monitor environmental quality, since it directly correlates with the natural variations of the environment. Note, however, that changes in environmental characteristics, aside from those within their natural amplitudes, can be reflected at other levels of the biological organization (Val et al. 2003).

The biotic ligand model predicts the amount of bioavailable ions that can cause toxicity to aquatic organisms. In order to do so, the model takes into consideration several physical-chemical characteristics of the aquatic environment, including the varying "quantity of dissolved organic carbon", which previous models did not do. The implementation of this model for fish in three different environments in Amazonia showed that the sensitivity of these animals to copper is strongly related to the levels of calcium and dissolved organic carbon in the water (Bevilacqua 2009). This model, in addition to defining molecular bioindicators for monitoring of environmental quality, is of extreme importance for Amazonia because a number of anthropogenic pressures can already be noted in the area.

Functioning of Water Systems

Due to the seasonality of rainfall, the large rivers of the region have flood pulses with cycles of high and low water levels that constitute the main driving force of the Amazonian system. Flooding can last several months. In wetlands, the interaction between the water body and the biota in the edge areas is decisive. Allochthonous primary production of riparian forests is of great importance for the food chains both in the water bodies and in the floodplains. When the water recedes, the flooded areas can be reduced to only 20 % of the total area of the aquatic phase, resulting in important ecological implications. The suppression of environments breaks the connectivity between individuals, confining and isolating organisms of many species. These communities respond adaptively to the special conditions created by the flood pulses. Many trees in the wetlands form growth rings (because of reduced rates of growth) as a response to flooding (Worbes 1997), which allows this information to be used in managing these areas, which are currently threatened by agriculture and the inadequate use of natural resources (Junk 2000) (Figs. 6.1, 6.2, and 6.3).

The changes of global climate will also affect Amazonia, where significant decreases of rainfall are predicted, at least on the eastern side of the watershed, as well as an increase in the effects of events such as El Niño and La Niña. In addition, the forecasts indicate (Junk et al. 2009):

1. That the humid coastal areas will be affected by rising sea levels and that the occurrence of fires will increase in an alarming way.
2. That the small streams and their flooded areas might dry up completely during the dry season, with severe consequences for the fauna and flora.
3. That the disconnected areas in the interfluves, especially in the cerrado (central Brazilian savanna) will experience tremendous impacts, affecting the biodiversity of these locations.

The humid areas along large rivers are relatively flexible. However, protection systems for the local human population are necessary, such as robust programs to predict the levels of the river (Schöngart and Junk 2007), so that economic activities like fishing, agriculture and timber extraction can be done in line with the fluctuations of the levels of the rivers. However, prior to the impacts of climatic changes being felt, the inadequate management of the ecosystem in flooded areas will cause significant imbalance (Junk et al. 2009).

Fig. 6.1 Spillway of the Tucuruí Dam in the Tocantins River, state of Pará. Water leaves the reservoir at a depth of 20 m, where it carried great quantities of methane. Pulverization in the form of droplets releases this greenhouse gas in the atmosphere, contributing to global warming (photograph by Philip M. Fearnside)

Diversity of Aquatic Organisms in Amazonia

In general terms, the aquatic diversity in the Amazon is composed of the same groups that are widely distributed throughout the world, in other words, by algae, surface plants, sponges, rotifers, insects, mollusks, crustaceans, amphibians, reptiles, birds, fish, and mammals, highlighting that some of these groups live in water, but spend some time on land and vice-versa. The last three of these and the aquatic plants deserve special attention due to the biomass they represent.

The fish of Amazonia stand out due to the enormous variety of species found there. They constitute 10 % of the world's freshwater ichthyofauna or 80 % of Brazilian ichthyofauna. More important is the fact that the fish constitute the main source of food, employment, pleasure and income of the local population, whose per capita annual consumption is of 100 kg, or more than six times the world average. Without a doubt, the fishing industry (including the resources from sport fishing, ornamental fish fishing and fish farming) constitutes one of the mainstays of the economy in Brazilian Amazonia, creating over 100 thousand direct jobs (Cabral Jr. and Almeida 2006) and about ten times this amount if indirect jobs are considered.

The chelonians, especially the turtles, stand out for their historical and cultural importance in human nutrition, not only in the form of eggs, but also in the form of meat. Because of the pressure of fishing and of the destruction of the aquatic habitat

Fig. 6.2 Place originally chosen for the Jirau Hydroelectric Dam, Madeira River, state of Rondônia (during the low-flow season). The Madeira River carries large quantities of sediments, a factor that aggravates the formation of a backwater stretch that is expected to cause flooding in Bolivia in the river stretch above the reservoir (photograph by Philip M. Fearnside)

in which they live and nest, one of the 14 Amazonian species, the tracajá *Podocnemis inifilis*, is on the IUCN list (International Union for Conservation of Nature) as a vulnerable animal. The alligators, represented by four species (*Caiman crocodilus*, *Melanosuchus niger*, *Paleosuchus palpebrosus* and *P. trigonatus*) have an important role in the ecosystem as head of the food chain and as voracious predators. They have been hunted for decades for their skin and for their meat, which is used in the local cuisine.

The mammals stand out for their large sizes and for the fact that one of the five existing species in the region's aquatic ecosystems, the giant otter (*Pteronura brasiliensis*), is currently on the IUCN list as an endangered species. The other four species (manatee *Trichechus inunguis*, otter *Lontra longicaudis*, tucuxi dolphin *Sotalia fluviatilis* and the Amazon River dolphin *Inia geoffrensis*) are listed as insufficiently known. Despite this, they continue to be hunted.

The macrophytes stand out for being primary producers, from which organic matter originates and becomes the main link in the food chain. They are particularly important in the floodplain ecosystems, where the *Paspalum repens* and *Echinochloa polystachia* wild grasses predominate. This last one is one of the plants with the highest known productivity (100 t ha^{-1}) and a solar energy conversion factor of 4 % (Piedade et al. 1992). Aside from their role as a food source, these plants supply refuge to a multitude of organisms that live in out of the water.

Fig. 6.3 Samuel Reservoir, on the Jamari River, state of Rondônia. Decomposition of dead trees releases CO_2, which contributes to global warming (photograph by Philip M. Fearnside)

The environment of each species is a complex set of chemical, physical and biological factors that interact throughout the evolutionary process, supplying the conditions for life and determining the ranges of these species. It is also through the interactions among species, populations and communities that the relations of predation, competition, parasitism and symbiosis are developed, which in Amazonia take on huge proportions.

In spite of the importance of aquatic biodiversity, or maybe because of its importance, the aquatic biota in Amazonia has been suffering extreme pressures, alterations and losses. Its balance, already fragile, runs the risk of being broken. Among the many causes, deforestation and the many problems that result from deforestation, such as siltation, alterations and elimination of habitats and the pollution of steams, especially of those that run through cities, stand out and need to be assessed and have measures taken in order to completely eliminate them.

Function, Valuation and Social Issues

In Amazonia, water is primordial to humans because, aside from its physiological function, it represents the most important means of transport, the main source of energy and of food. However, the use and the exploitation of water can cause social impacts. The calculation of the value of these resources in large projects should include the social costs.

Domestic consumption of water by the human population of Amazonia is very small when compared to the volume of water that exists in the region. Nevertheless, water suitable for consumption in Amazonia can become scarce due to environmental disturbance, including pollution, and due to episodes of infections and parasites in rural and urban populations.

Transportation by water is the only way or reaching many parts of Amazonia. The majority of human settlements are located along the navigable rivers and the waterways are important for the populations to access their homes. Although it might seem like an activity that does not damage the environment, the waves created by the transit of boats can affect areas on the river banks.

With regards to generating energy, the hydroelectric potential of the Brazilian Amazonia is very large due to topographical slopes along the tributaries of the Amazon River, starting from the Brazilian Shield (on the southern part of the region) up to the Guiana Shield (on the northern side). The hydroelectric development plan for Amazonia is enormous: 68 hydroelectric dams were expected in the "2010 Plan". However, the social and environmental problems caused by hydroelectric dams are also enormous. The relocation of rural and indigenous populations from the areas of the reservoirs can result in severe impacts in some places. The Tucuruí Dam, on the Tocantins River, flooded part of three indigenous reserves (Parakanã, Pucuruí and Montanha) and its transmission lines crossed an additional four reserves (Mãe Maria, Trocará, Krikati and Cana Brava). There is a disparity in the magnitude of costs and benefits, with great inequalities with regards to who pays the costs and who collects the benefits. Local populations frequently suffer the main impacts, while the rewards usually benefit large urban centers, and in the case of the largest dam of them all (Tucuruí), the benefits are for other countries (Fearnside 1999, 2001).

The electricity generated by Amazonian dams, usually does very little to improve the quality of life of the people who live near the projects. The Tucuruí Dam supplies subsidized energy to multinational aluminum plants in Barcarena, in the state of Pará (ALBRÁS and ALUNORTE, of Nippon Amazon Aluminum Co. Ltd. or NAAC, a consortium of 33 Japanese companies) and in São Luis, in the state of Maranhão (ALUMAR, of Alcoa), while the populations that live near the project use querosene lamps for lighting.

Hydroelectric dams also cause health problems for the populations who live there, such as malaria and arboviruses. Malaria is endemic in the areas where the dams are built, and incidence increases when populations migrate to these areas. The environmental imbalance can cause these diseases to increase by increasing the number of vectors (Tadei et al. 1983; Tadei et al. 1991). Another problem is mercury methylation, which occurs in hydroelectric reservoirs as indicated by the elevated mercury levels in fish and in human hair in Tucuruí (Leino and Lodenius 1995). High concentrations of Mercury are found in Amazonian soils, which originated millions of years ago (Roulet et al. 1996; Silva-Forsberg et al. 1999). Other water uses can also result in social and economic asymmetries. Water resources are essential for the production of food, both on land and in aquatic ecosystems. Irrigation, however, still only affects a small portion of the agriculture in Amazonia, although this could change in the future. The most famous large-scale initiative in Amazonia was the now-abandoned rice irrigation project at Jari (Fearnside and Rankin 1985; Fearnside 1988). The provision of water for cattle represents a significant alteration of the water resources in deforested landscapes. This water is mainly supplied by small reservoirs created by damming streams that run through pastures. The lack of water is already a limitation on fishing in dry years. On the other hand, at the interface between terrestrial and aquatic environments the deposition of nutrients by sedimentation during the flood periods is essential to agriculture in the Amazonian floodplains (Junk 1997).

Lastly, it is important to mention the role of Amazonian water in the climate and in the maintenance hydrological parameters in several regions of the country. Aquatic ecosystems in Amazonia are linked to the regional water cycle and to the transportation of water vapor to neighboring regions, including the central-south of Brazil (Fearnside 2004). The water enters the region in the form of vapor coming from the Atlantic Ocean. Prevailing winds in the area run from east to west, and much of the water that falls as rain the region is returned to the air by means of evapotranspiration (Salati 2001). When the air reaches the Andes, a significant part is directed to the south, taking the water vapor to the Brazilian central-south and to neighboring countries. Models indicate that approximately half of the water vapor that enters Amazonia is transported out of the region to the south, by means of wind (Marengo et al. 2004; Correia et al. 2006; Marengo 2006; D'Almeida et al. 2007).

Amazonian aquatic ecosystems also play an important role in the global carbon cycle. The sediments from the Andes and from soil erosion within the Amazonian region are transported to the ocean by the Amazonian rivers, especially by the Madeira, Solimões (upper Amazon) and Amazonas (Lower Amazon) Rivers. These sediments, which can be deposited and remobilized in the floodplains, carry a significant amount of carbon. Dissolved organic carbon enters the rivers through terrestrial runoff and from water from the soil throughout the region, and it represents an important carbon flow to the oceans. Large quantities of CO_2 are released from the water in the Amazon River (Richey et al. 2002). Nutrients, which are also transported by the Amazon River, sustain the high productivity of plankton in the estuary of the Amazon River and the consequent removal of atmospheric CO_2 by ocean sediments (Subramanian et al. 2008). Hydroelectric dams can cause the rupture of these flows and increase other greenhouse gasses such as the methane (Kemenes et al. 2007).

Waters of Amazonia and International Environmental Law

The Amazon Hydrographic Basin is the most extensive hydrographic network on the globe and runs from the Andes to the Atlantic Ocean (Eva and Huber 2005). As it was already mentioned this basin of continental dimensions affects several countries of South America.[1] The issue of water in Amazonia and international environ-

[1] One should not confuse the Amazonian Hydrographic Basin (international hydrographic basin) with the Amazonian Hydrographic Region, which is made up by the hydrographic basin of the

mental law requires a plural analysis of the normative space and of the region's cultural diversity. As the poet Thiago de Mello says, the water regime corresponds to one element within the life of humans in which the economic cycles are determined by: large ebbs, bountiful harvests (great times for fishing and for planting), major floods, severe calamities and bitter miseries (the fish disappear from the river, the plantations are destroyed) (Mello 2002). With regards to international environmental law, we should consider three perspectives:

1. The multinational nature of the basin.
2. The biological migrations.
3. The shared and sustainable use of the region's resources.

The notion of an "International river", referring to navigable rivers that cross or separate the territory of two or more states, has changed with the acknowledgment of the concept of international water flow and international hydrographic basin. However, no consensus exists, either in theory or in practice, with regards to the extension of these expressions. The "Helsinki Rules" regarding the use of water in international rivers, adopted in 1966 by the International Law Association and reviewed in 2004 by means of the "Berlin Rules" had the objective of regulating and protecting the use of continental waters. The concept of an "international river" was essential in the formulation of the rule of equitable utilization of transboundary waters, as well as in the development of protection rules for continental waters and shared natural resources (Silva 2008a), where, in the context of the revision of these rules, there was an acknowledgement of the ecological integrity of the waters in three dimensions: biological, (2) chemical and (3) physical, without disassociating these features from the social and economic dimensions.

The 1997 United Nations Convention on the Use of International Watercourses for Navigation did not adopt either the concept of International River or of International Hydrographic Basin (McCaffrey 2001). It did, however, adopt the concept of international watercourse as "a system of surface and ground waters constituting, by virtue of their physical relationships, a unitary whole that flow into a common terminus".[2] This Convention established the need for: (1) the equitable and reasonable use and participation; (2) the general obligation to not cause significant damages; (3) the obligation of cooperating, founded on sovereign equality, territorial integrity and mutual benefit; (4) the regular exchange of data and information on the quality of waters; and (5) the principle of equality among all uses.

The Amazonian Cooperation Treaty (TCA) was signed on July 3rd, 1978 by the Republics of Bolivia, Brazil, Colombia, Ecuador, Guiana, Peru, Suriname and

Amazon River located in the Brazilian territory, by the hydrographic basins of the rivers at the Marajó Island, aside from the hydrographic basins of the rivers located in the state of Amapá (which flow into the North Atlantic), totaling 3,870,000 km^2, according to the National Hydrographic Division (Resolution of the National Council of Water Resources CNRN number 32, of October 15, 2000).

[2] Two types of aquifers are excluded from the definition: those that are not rechargeable and those that are connected to a water body.

Venezuela, with the objective of promoting the harmonious development of their respective Amazonian territories and the assertion of national sovereignty over natural resources, entered into force on August 2nd, 1980. The concept of the "Amazon Basin" encompassed not only the international hydrographic basin, but also their eco-regions (Silva 2008b). The TCA addresses the functions that the Amazon River and the other international Amazonian rivers have with regards to communication among the countries, and the reasonable use of the water resources, without, however, establishing specific criteria for reasonable use. The Protocol of Amendment to the Treaty of Amazonian Cooperation, adopted in Caracas on December 14th, 1988, and which entered into force on August 2nd, 2002, instituted the Organization of the Amazonian Cooperation Treaty (OTCA), a legal entity that is competent to enter into agreements with contracting parties, with non-member states and with other international organizations (Silva 2008c). TCA and OTCA have as their primary function the production and diffusion of information, and they act as an international political forum. Since there is no rule for the resolution of disputes or for delegation to the OTCA, domestic legal norms regarding environmental issues have an essential role in regulating the means of appropriation and use of natural resources in the region.

Among the biological migrations in the waters of the hydrographic basin of Amazonia, that of the giant catfish stands out, especially the dourada and the piramutaba, whose stocks are economically important for Brazil, Colombia and Peru and, to a lesser extent, in Bolivia and Ecuador. Throughout their lives, the migrating catfish swim through the main white water rivers of the Amazonian basin, crossing both state and international borders (Vieira 2005). Current knowledge about the migration of these species suggests that they migrate from Brazil, along the Amazon River and up the Madeira and Solimões rivers to their spawning areas in Bolivia, Colombia and Peru (Ruffino 2000). Although one can identify informal agreements for the periods of closure of fishing for certain species like the Arapaima in the region of the frontier between Brazil, Colombia and Peru (Vieira 2005), there is still a need for adoption of legal norms for the management of shared fishing resources, as well as for allocating financial means and human resources to control the fishing industry.

The provisions of the Amazonian Cooperation Treaty establish the preservation of the species in the region by means of promoting "scientific research and the exchange of information and of technical personnel among the competent entities of the respective countries, in order to increase knowledge about the resources (…) about the fauna in their Amazonian territories, which will all be articles of an annual report presented by each country" (art. VII). In addition, the Commission on Continental Fishing, in its Tenth Meeting, held in Panamá 7–9 September 2005, recommended:

1. The acknowledgment by the governments of Latin America, of the social, economic and environmental value of continental fishing.
2. The strengthening of institutional and local (communitarian) capacities for the ecosystem management of fishing.
3. The strengthening of cooperation among countries for the management and sustainable use of shared basins.
4. The development of integrated assessments to optimize recreational fishing in shared basins.

5. The improvement of data collection and the development of tools to facilitate the management of data bases.
6. The creation of areas of biological conservation in shared basins.

And lastly, infrastructure projects and potentially pollutant activities need to be submitted to studies of environmental impacts.[3]

The concept of shared natural resource was included in international law through the Letter of economic rights and obligations of the States, which established on one hand, the obligation to cooperate in the exploitation of shared natural resources, and, on the other hand, the principle of permanent sovereignty of the States over the natural resources in their territories. The nature and spatial extent of human actions in these areas constitute the subjects of fruitful and profound studies in the sciences, especially in the natural, human and social science areas. The regularizing of these spaces and of the human relationships that transform them require studies, reflections and the creation of legal norms, which need to be taken into account by the law.

Throughout history, Amazonia has always been the stage for paradoxes, and there have been frequent mistaken ideas, and there have been many fights and disputes over the control and appropriation of these riches. It is in this latter sense, regarding control and appropriation of wealth, in this case of everything that is found in its water or that interacts with it that one must consider the biological totality that is found in Amazonia, and these concerns take on a political nature. Thus, Amazonia becomes the subject to different regulatory implications, whether formal or not, both within the internal scope of national states and in the context of international communities of sovereign states.

For Amazonian aquatic areas, the determination of physical borders for the use of transboundary biological resources encounters its first material obstacle in the nature of Amazonia itself, where water predominates, dominates and determines the universe of social and political relationships (Tocantins 2000). Firstly, because Amazonian borders involve peoples with special relations to the state, including indigenous populations and those of the traditional populations; secondly, because the different ways of using the waters, imply in different forms and aspects of regulation. In legal terms, the use of transboundary biological resources is controlled by the Convention on Biological Diversity (CBD), adopted by Brazil and promulgated by Decree number 2519, of March 16th, 1998. The CDB is, within the hierarchical system of norms, an international treaty with the aim of promoting the conservation of biological diversity, the sustainable use of its components, and the fair and equal

[3] One can cite the "Madeira Complex", a set of infrastructure projects involving four dams, forming a complex of four hydroelectric plants and a navigable waterway network of 4200 km, within a future program of transport infrastructure and energy integration between Brazil, Bolivia and Peru, aside from the transmission line associated this river stretch. Neither Peru nor Bolivia were consulted about this project, and despite the negative transboundary impacts, a preliminary environmental license was issued for the first two dams of the "Madeira Complex", with 33 constraints imposed by IBAMA, of which the majority relate to the three issues which previously provided the foundation for the denial of the same license: (a) issues related to sedimentation, (b) issues that indicate the possibility of mercury contamination and (c) issues concerning the effects of the dams on ichthyofauna in the region (Silva 2008b).

partition of the benefits that result from the use of genetic resources, establishing principles, norms and scopes of jurisdictions.

Thus, the protection and conservation of the waters of Amazonia require a vision of the hydrographic basin in its totality, as well as an understanding of the intrinsic relationship of the hydrological cycle of waters, forests, biodiversity and social aspects with regards to the different visions of water and the different ways of living and using. One should also take into consideration the legal norms of the countries in the region, as well as the sources of international law on which international environmental treaties are founded, and of which the countries of the region are members.

Future of Water Systems of Amazonia

The waters of Amazonia represent an environmental, economic and social asset that requires extensive studies embracing its entire dimension in order to enable safer interventions, in such a way as to allow these resources to be used and conserved. The Amazon biome cannot be considered in a fragmented way. There is a need for integrated actions in the entire system, which demands for a set of agreements with other countries and therefore interventions from specific spheres of the governments of these countries. The progress of these agreements will depend upon robust information, which allows for agreements with ample scope. Undoubtedly this in itself is one of the first limitations: there is very limited installed capacity in the institutions of the region, whether Brazilian or in the other countries in the Amazonian region, to produce this information.

In Brazilian Amazonia there is only one specific post-graduate program that is focused on training personnel for the study of water in the region: the Freshwater Biology and Inland Fisheries program at INPA. The study of water of Amazonia, in its many dimensions, is done in this and in other programs, such as the post-graduate programs in Ecology (INPA), Fisheries Resources (UFAM) and Climate and Environment (INPA-UEA). These programs, despite being in high demand, have limited capacities due to the number of professors available. Even so, a considerable number of professionals have been trained and these people work not only throughout Brazil but also in neighboring countries. Scientific cooperation with other countries has had an important role, as exemplified by the almost 50 years of agreement of cooperation between INPA and the Max-Planck Institute.

The current demand for information involves, aside from basic studies on environmental dynamics, those on advanced modeling. These studies need to provide information for the decision-making process regarding the new hydroelectric dams planned for Amazonia, the mining activities (including petroleum), the opening of new roads, the management of aquatic species of commercial importance, and the use of watercourses for transportation and communication. In addition, the use of modern technology for the development of new products and processes, based on the biological and chemical diversity of aquatic environments of Amazonia, is vital.

Initial tests revealed the existence of millions of dissolved organic compounds in the waters of the Negro River alone. These need to be analyzed in order to discover their origin and organic properties. The expansion of these studies to other aquatic environments of Amazonia is necessary.

Therefore, people from the region need to be at the core of the studies of the aquatic environments of Amazonia. In Brazilian Amazonia alone there are about 25 million people who have water as their main source of life, of their interactions with the environment, of their food supply and of their coming and going. Basically, humans are in Amazonia a central aspect of the aquatic environments of this vast region.

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Chapter 7
Urbanization and Water Resources

Carlos E.M. Tucci

Abstract The world is slowly becoming urban as a result of economic development and distribution of jobs. In developed countries, population is stabilized and the urban population is already a large one, but in countries under development, the urban population is increasing and by 2050 the world's population should be of about nine billion with the majority of the growth occurring in the cities. Urbanization increases the competition over the same natural resources (air, water and land) within a small space, for all human needs of life, production and recreation. The environment, formed by natural space and by the population, is a living and dynamic being that generates interconnected effects, which if not controlled, can lead the city to chaos. In the urban environment, the modifying force is urbanization. Water infrastructure usually includes water and sanitation. Commonly, sanitation refers only to the collection and treatment of domestic and industrial effluents, and do not include drainage and solid wastes. The services of Urban Waters, supplied by the city should include water supply, sewage system and treatment, draining and solid wastes. These are components of a sustainable urban environment that takes into consideration environmental conservation, health and socioeconomic aspects of urban development. The main problems related to the city and to these elements have been managed in a fragmented way. The Urban Master Plan usually does not associate all the infrastructures to urban waters. The management of urban waters is also fragmented since there is not an integration of services, or a unique company managing the set of services. The results are poor with no indication of efficiency. This article presents a vision of unity of the main aspects related to the development of urban waters and its sustainability. Based on the problems found, we have presented the guidelines for an Integrated Urban Water Management and the necessary elements to plan for these services aiming at obtaining the main goals of water management, which are, basically to improve the quality of life and protect the environment.

Keywords Management • Sustainability • Urban • Water

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Population and Urbanization

Urbanization is the process of economic and social development resulting from the transformation of a rural economy to an economy of services concentrated in urban areas. This process was striking in the twentieth century. In 1900, 13 % of the global population was urban. In 2007, the urban population was 49.4 %, occupying only 2.8 % of the entire global territory (Table 7.1). In 2050, the estimate for the world's urban population is of 69.6 % (Table 7.1), of which the entire population growth from six to nine billion people will be for urban areas, in addition to the part of the rural population expected to move to urban areas.

The world is becoming urban as a result of economic development and an increase of job opportunities in the cities. Developed countries no longer present population growth, only growth based on immigration, therefore, the entire expected population growth will be in agricultural and poorer countries. One can observe though this process, that urbanization is an inhibitor of population growth, since as urban population increase, birth rates decrease. Usually, population becomes stabilized when it reaches 2.1 children per couple, becoming less with the passing of generations, which is when it falls to below this number. On Fig. 7.1, one can observe the reduction of population growth with the urbanization in countries of South and Central America.

Brazil has grown from 90 to 190 million since 1970 and the urban population went from 55 to 83 %. This means that 158 million people live in the cities, occupying 0.25 % of Brazilian territory.

Urbanization Processes

Urbanization increases economic development, changing it from an agricultural economy to an industrial and service economy. Great urban agglomerates were formed. Currently, there are 388 cities in the world with more than one million inhabitants and 16 with more that ten million, and in 2010, 60 cities are expected to have a population of more than five million (McGranahan and Marcotulio 2005). There is a strong correlation between the density of the population and economy,

Table 7.1 Distribution of worldwide population (UM 2009)

Region	Urban %		
	2007	2025	2050
World	49.4	57.2	69.6
Best developed regions	74.4	79.0	86.0
Not so well developed regions	43.8	53.2	67.0
Under developed countries	27.9	38.1	55.5
Other under developed countries	46.5	56.4	70.3
Least developed, excluding China and	44.1	52.1	65.7
Sub-Saharan Africa	35.9	45.2	60.5

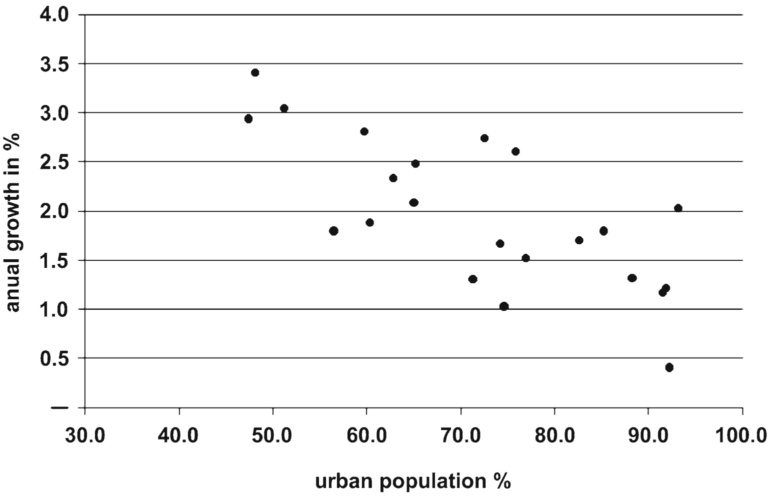

Fig. 7.1 Population growth and urban population

Fig. 7.2 Metropolitan areas (WDR 2009)

which explains why urban areas are centers of production, purchase and sale, businesses and workers. The GDP of a country increases with the increase of great centers. Countries with high income have 52 % of its populations in large cities (>1 million) and countries of low income have only 11 %. Brazil has 27 % of its population in cities with over 500 thousand inhabitants.

Urban growth in Brazil has occurred mainly in metropolitan regions (RM) and in cities which are regional poles. Metropolitan regions have a core group (primary city) with several neighboring cities (secondary cities, Fig. 7.2). The growth of the core group tends to decrease with time, while the periphery grows in an accelerated way. In Brazil, the cities with over one million inhabitants grow at a 0.9 % rate per year, while cities which are regional centers (100–500 thousand inhabitants) grow at a 4.8 % rate (IBGE 1998). At a global level, the cities with >500 inhabitants represent 46 % of the total population. Secondary cities and towns are the interconnections between urban and rural areas.

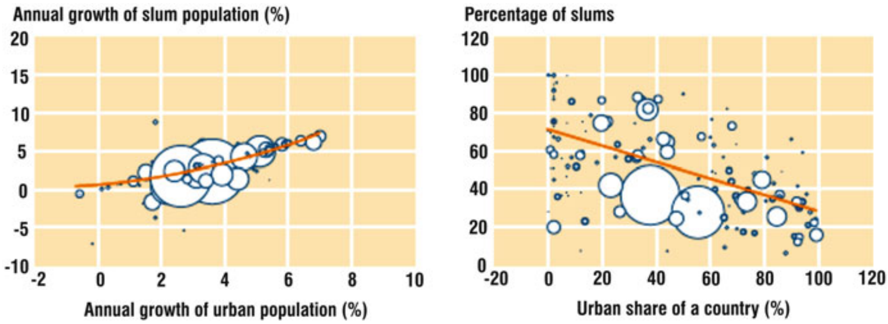

Fig. 7.3 Growth of favelas resulting from urbanization and their decrease as levels improve (WDR 2009)

Urbanization in Brazil, as in other countries under development, has been occurring in a spontaneous way, despite the existence of the Urban Master Plan. What can be observed is a part of the city which is built and managed, in the majority of the cases, within the norms and standards specified in the Master Plans, the so-called "legal city"; and a part of the city that expanded in an illegal way by the poor population, in the form of "favelas", in other words, typically public areas invade and allotted at random, with no infrastructure with a disorders street layout, when there are streets.

Figure 7.3 shows how favelas grow in conjunction to population growth and how it decreases as the country becomes more urban. As countries become urbanized, they tend to become richer. Delhi, in India, has 1160 groups of favelas within a total population of 15.6 million (WDR 2009).

The main problems related to infrastructure in countries under development are:

1. Large number of people in a limited space with inadequate public transport, water and sanitation, air pollution and floods. This inadequate environment decreases population's health conditions and quality of life, increasing the impacts on the environment.
2. Increase of city limits in an uncontrolled manner due to rural migration in search of job opportunities. Manaus, for example, in 2004 received about 40 thousand immigrants attracted by job opportunities. This occupation occurred in the areas of the watershed, contaminating this source of water supply. In this type of neighborhood, usually there is a problem of safety, infrastructure and the area is dominated by criminal groups related to drug dealing.
3. Urbanization is spontaneous and urban planning is focused towards the population with medium income. The favelas develop in an informal manner, through the invasion of public areas by the poor population, or organized by speculators for this type of population. Part of the invaded areas is subject to floods and landslides.
4. Urban Planning is done for the formal city, while the informal city is developed without any control, in public areas close to the availability of service for the low income population.
5. Limited institutional capacity of the cities with regards to legislation, Law enforcement, maintenance and technical economic support.

6. Lack of integrated management of urban waters: the management of the water infrastructure is done in a totally fragmented way, resulting in low quality services when they exist.

Uses and Impacts of Urbanization on Water Resources

General View

Urban development is a geographic process, since in many cities, development occurs from downstream to upstream in the basin and from the coast to the interior in coastal cities. Water is supplied from existing sources upstream or from neighboring basins, or ever from ground water (or the combination of them all). After the water has been used by the population, it returns to the rivers without any treatment, or via the overflow of septic tanks. Sewage then pollutes the rivers, which no longer can be used as a supply source. Water supply systems try to use water from sources that are not polluted, throwing the polluted water downstream. Since development occurs upstream, with time, the existing sources become contaminated by new developments, aside from competing with agriculture for use of water. When the city no longer has the capacity of supplying water to the population, people find their own means of obtaining water, by perforating wells or purchasing water (exponentially increasing the cost of water). The poor population tends to perforate shallow wells, which have already been contaminated by sewage while the high income population perforates deeper wells, which are safer, but can lead the lowering of the terrain due to depletion. In coastal regions, this can lead to salt water intrusion.

Urbanization also increases impervious areas and channeling, which increases its peak flows and runoff frequency for the same amount of rainfall. Urbanization also increases the speed of water and the sediment yield and solid wastes that flow into the drains. Due to the lack of cleaning services and maintenance, these solids reduce runoff capacity and increase pollution, also due to the washing off of impurities from urban surfaces (great quantities of metals).

Pumping water from the underground together with the reduction of infiltration due to impervious areas, can lead to the lowering of the terrain, worsening the conditions of floods in low areas, aside from affecting the tides in coastal cities.

Summarizing, urban waters in countries under development are in a sort of contamination cycle and their main problems are as follows (Fig. 7.4):

1. Contamination of the supply sources (rivers and ground water) due to urban development and discharge of untreated effluents into rivers that flow into water sources.
2. Lack of sewage treatment: a large portion of the cities do not have a sewage collection or treatment plant. Sewage is discharged into rivers without treatment, polluting urban rivers and destroying the environment.
3. Urbanization increases impervious areas, causing the increase of floods and the decrease of infiltration to aquifers. Impervious areas and channeling of urban

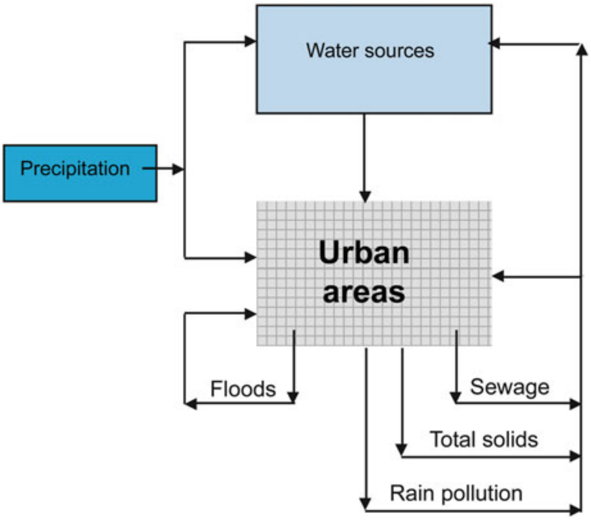

Fig. 7.4 Cycle of urban contamination in countries under development

rivers increase in about seven times the amounts of floods, the sediment yields and the quality of rainwater.

4. Occupying areas at risk such as, for example those subject to flooding and those subject to landslides of slopes.
5. Contamination of rivers due to urban rain water and agriculture.
6. Removal of ground water together with the reduction of infiltration produces the lowering of the terrain and increases floods in low areas.
7. The lack of services for solid waste decreases the river's capacity due to sedimentation, increasing floods.

The combination of all these factors renders urban areas at risk. Considering that the urban area is the economic motor of the country, this unsustainable condition can lead to an important risk to the country's development.

Main Risks

The main source of the problems is an urban development without any control. The main risks are:

Population's health: some of the risks are: (a) the lack of treatment of effluents and lack of collection and disposal services of solid wastes, produces a source of internal contamination of cities, which helps spread diseases and epidemics; (b) contamination of the sources of water like reservoirs, by nutrients, allowing the development of algae and toxicity in supply water; and (c) diseases that spread due to lack of hygiene and through water contamination, such as dengue, leptospirosis, diarrhea, hepatitis and cholera, among others.

Floods: increase in the risk and in the frequency of floods, economic and social vulnerability of the population.

Deterioration of the environment: degraded areas due to erosion, environment of rivers and coastal areas, decreasing recovery capacity of these environments due to the elevated levels of pollutants.

Reduction of safe water: the scarcity of safe water, leads populations to seek alternatives which are always more expensive. The international price of 1 m^3 of water is of US $ 1.00 to US $ 3.00. In Brazil, 20 L sold to houses cost about US$ 200.00 to 300 m^3.

General: increasing population's vulnerability, the reduction of resistance depends upon the how urban development occurs.

Integrated Management of Urban Waters

Management Structure of the City

The structure of the Management of Rainwater is based on the following set of components (Fig. 7.5):

Urban Planning: discipline regarding the use of the soils of the city, based on the infrastructure needs.

Urban Water Services: water supply, sanitation, solid waste and urban draining.

1. Goals of services: conservation of urban environment and quality of life that includes the reduction of floods and the elimination of waterborne diseases.
2. Institutional: is based on the management of services, on legislation, on capacity building and in monitoring in general.

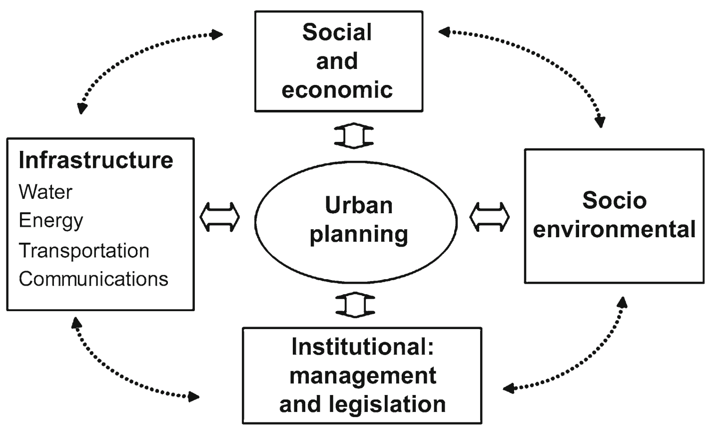

Fig. 7.5 Structure of integrated management

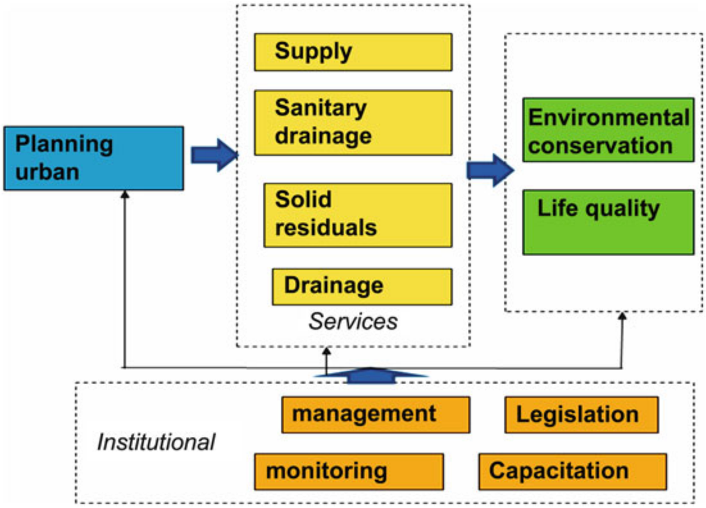

Fig. 7.6 Structure of the components of urban integrated management

Management of the city regarding water infrastructure requires: (a) use of the soil (an external agent of the water system); (b) city services (supply, sewage, draining and solid waste); and (c) goals (environment: conservation of the urban environment and of the population's health) (Fig. 7.6).

The Services

The city services, foreseen in the National Sanitation Policy are the following:

1. Water supply: involves the delivery of safe water to the population and involves the following components: conservation of the watersheds, regulation, adduction, water treatment and distribution.
2. Sanitary sewage: sewage collection, treatment and disposal of sewage in the water system.
3. Urban draining: rainwater collection system, transportation and disposal in water system.
4. Solid wastes: collection of wastes, cleaning of streets and disposal of wastes.

On Fig. 7.6, all the main relationships between the infrastructure systems of the urban environments and water, are characterized. The urban development, represented by soil occupation is the main factor of impact.

Next we will discuss the interactions generated between the water systems in the urban areas due to a deficient and poor management which are:

1. Urban Supply: the key interfaces with the other systems are: (a) sanitary and rain sewage can contaminate surface and underground watersheds; (b) the deposit of solid wastes as landfills can contaminate the watershed areas; and (c) floods can stop the supply system and destroy the infrastructure of rainwater and sanitary networks, aside for the Sewage treatment plant.
2. Sanitary Sewage and urban draining: the main interrelations are: (a) when the system is a mixed system, the transportation system is still the same, with diverse behavior during the periods with rain and without rain, and management should be integrated; and (b) when the system is split, there are interferences in management and with regards to constructions due to the connection of the sanitary sewage to the draining network and rainwater in the sewage system causing inefficiency in its functioning.
3. Urban draining, solid waste and sanitary sewage: (a) when the collection system and the cleaning of waste is inefficient, there is great loss of the rain runoff due to obstructions of the conductors, channels and urban streams; and (b) urban erosion changes the draining system and can destroy the sanitary sewage system.

These services aim at quality of life (health and safety with regards to floods) of the population and the environment. In order to achieve these goals it is necessary to determine an institutional capacity that can ensure these services, meeting the expected needs. This capacity depends on: (a) Management: the institutions that perform the services and that control them; (b) Legislation: legal mechanisms that ensure the services, meeting the expected goals; (c) Support Programs: are programs that support the management and the implementation of the legislation such as monitoring, capacity building, and the assessment of the indicators of the goals.

Integration

Integrated management (Fig. 7.7) deals with the development of the different components of urban management, starting from the planning of the urban space. An integrated vision starts in the planning of dismemberment and in the occupation of the space in the first phase of the allotment, when the project should aim at preserving the existing natural ravines. Contrary to what is currently planned, based only on the maximization of space exploration of the natural draining network, a sustainable project preserves the natural system and distributes occupation in smaller allotments, preserving a greater natural common area, removing the pavement edges from roads with low flux and integrating the asphalt to grass areas or other natural plant systems so that all the water can infiltrate.

With regards to sanitary sewage, one should create a connection between the sewage network and the adequate standard, which should be performed through the management of the water and sanitation services company. By doing so, one avoids inadequate connection and achieves sewage treatments of adequate standards, aside from being able to assess the treatments and the water systems which receive these effluents.

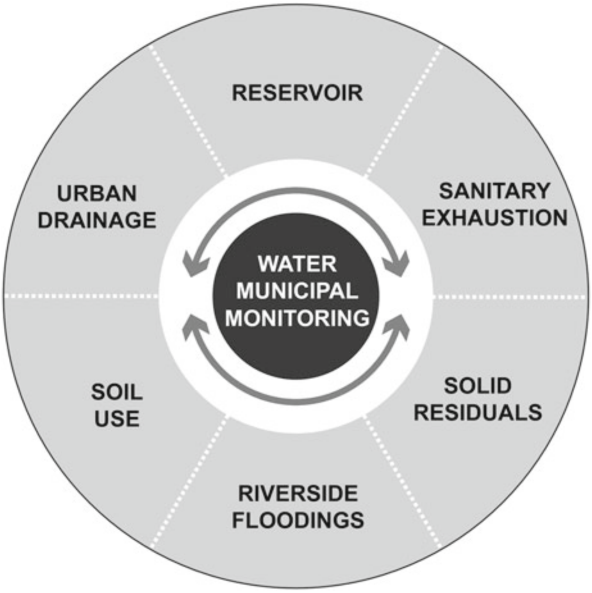

Fig. 7.7 Integrated view (Tucci 2005)

With regards to solid waste, one should aim at improving domestic collection and the cleaning of streets, the provision for automatic retention of garbage and the educate the population on economically efficient recycling systems.

Therefore it is necessary to develop strategies within the following main frameworks: (a) for new developments, seek to use the principles of a sustainable development, which are based on a sustainable occupation of space, on the elimination of pollution from effluents and on the reduction of waste, with a minimal use of energy and efficient transportation. The process can be developed partially with regulations (command-control) and partially through economic incentives for establishments, such as environmental certification; and (b) for existing cities, corrective measures should seek to work on urban water basins, in an integrated way, avoiding the transference of impacts. This planning should be performed within all the components of the services.

Environmental Sanitation Plan of Municipalities Characteristics

Preventive measures in urban development reduce the costs of the solution of the problems related to water. By planning a city with occupation areas and control of draining sources, with distribution of areas of risks and the development of supply and sewage systems, the costs will be considerably lower when crises occur, where currently the solutions for such problems have costs beyond the city's capabilities.

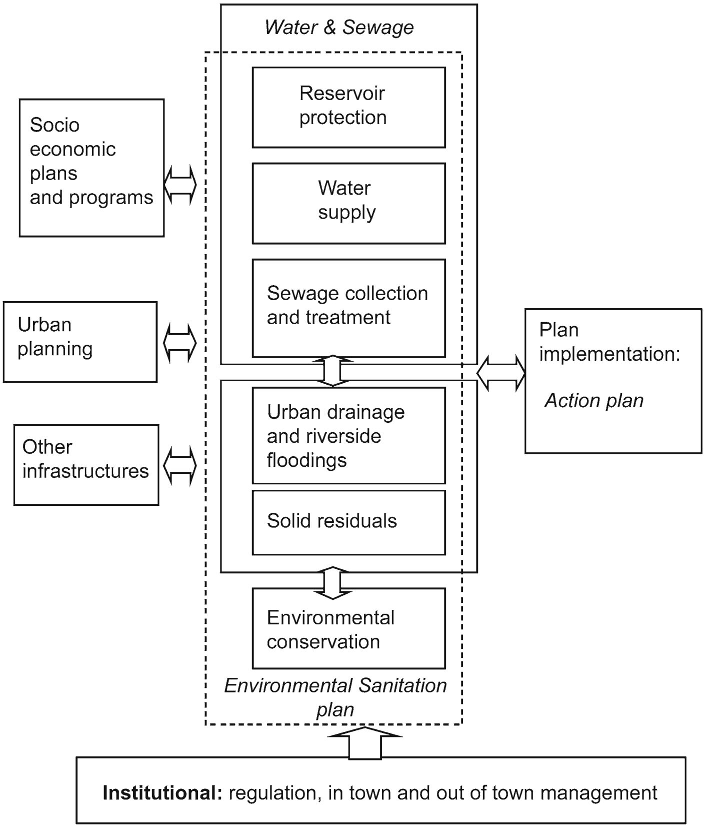

Fig. 7.8 Components of integrated management of environmental sanitation

Figure 7.8 and Table 7.2 characterize, in a broad way, the components of the Environmental Sanitation Plan. The great challenge is to develop an integration of these elements. The best way of obtaining this integration is to clearly define the goals which need to be attained for cities and the means that need to be developed in order to attain these goals. Based on these elements, one can see the interfaces of these planning components.

The general and specific objectives are presented on Table 7.3, and on Table 7.4, are the cause-effect-plan relationships. Goals are defined by means of objective indicators of each service, which can be determined by the Environmental Sanitation National Plan. These indicators should be few and should aim at efficiency and the conservation of water resources. While urban occupation has habitation density as their main indicator, which is directly related to water supply sewage and waste, they relate to the population as long as it is still possible to establish a relationship between habitation density and impervious areas—a factor with great influence over floods of on the system's capacity for urban draining. Similarly, impervious areas are a defining factor of environmental impacts.

Table 7.2 Characteristics of the city plan's contents

System	Action	Objective	Entity
Urban development	Soil use directive plan	Regulation of the occupation of the city	Municipality or Federal District
Water supply	Water supply directive plan	Increase the water attendance up to its total coverage	Municipality or State
Sanitation	Sanitation directive plan	Built a sewage collecting network and treatment plants aiming at improving the water quality and reduction of diseases	Municipality or State
Urban drainage and erosion	Urban drainage or rain water directive plan	Regulate the properties discharge and consequent erosion increase; control the impact of degraded and subject to flooding areas	Municipality
Solid residual	Solid residual directive plan	System of domiciliary collection, streets cleaning and final deposition of the residuals	Municipality
Environment	Environment directive plan	Recovery of degraded areas, conservation and planning of spaces	Municipality

Table 7.3 Objectives

Objective	Specific objective
Delivery of safe water for water supply, animal, industrial, commercial and agricultural consumption. Aquatic and terrestrial habitats conservation. Reduction of the population vulnerability to flooding risks and the water availability.	Development of new occupation patterns considering; (a) densification limits and impermeable areas; (b) destination of areas for parks and for dumping; and (c) use of economic mechanism to foster environmental medidas. Reservoir protection: (a) use of economic incentives to reduce occupation of reservoir areas; (b) control of discharges and occupation limits; and (c) to recover reservoir areas.
	Conservation and efficiency in the water supply systems to reduce their vulnerability.
	Treatment collecting systems based on the final objective of urban rivers sustainability and on the collecting and treatment efficiency.
	Urban drainage: control of the future impacts with regulation and of the present impacts with control measures in the watersheds.
	Solid residuals: reduce the amount of solid residuals in the environment and recycling.
	Conservation: eliminate degraded areas, avoid fragmentation of the urban environment and improve the quality control of rain water and sanitation.
	Recover the subterranean water recharge.

Table 7.4 List of causes and of plans

Main causes	Specific aspects	Plan
Unsustainable urban development	High density, impermeable areas, absence of the soil surfaces protection.	Regulation of urban waters for urban occupation.
Lack of urban waters services.	Population without water supply; lack of a net of collection and treatment of sewage; lack of collection and cleaning services of solid residuals; lack of the urban drainage management and flooding control.	Water and sewage.
		Solid residuals.
		Flooding management.
		Environment.
		Health.
Bad management.	Unsustainable works as canals, ducts, etc.	Institutional.
	Lack of legislation for the control of new developments.	

Aside from the impact and project indicators, it is necessary to identify the goals for the services for the objectives of the plan.

Action Plan

The development of the Environmental Sanitation Plan depends upon an Action Plan of the activities foreseen in it. On Fig. 7.9, a suggestion of the structure of activities of the Action Plan, distributed in short, medium and long term (with the period of time to be defined based on the situation), is presented.

Short Term: requires urgent measures, mostly non-structural, to contain potential future impacts resulting from urban development without sustainability.

Some of the actions are:

1. Protect watersheds: actions such as: (a) evaluate the levels of contamination in the water basins which are watersheds; (b) propose a control for the occupation of the basins of watersheds; and (c) propose priority actions to develop the Project and implement the sewage and treatment systems for the areas of occupation of the watersheds. This activity should be developed urgently in order to recover and avoid the contamination of water sources.
2. Proposal of Institutional Agreement: these activities should take into consideration the institutional aspects of the basin in order to propose management mechanism of the water basin and of urban waters; the main activities are: (a) legislation for urban draining, solid wastes and quality control of the water; and (b) legislation for the implementation an recovery of the costs of urban water systems.

Medium Term: a summary of these activities is as follows:

1. Water supply and sanitary sewage plan: this plan should have an Idea of integration
2. Since the actions should prioritize the recovery of the sources of water supply.

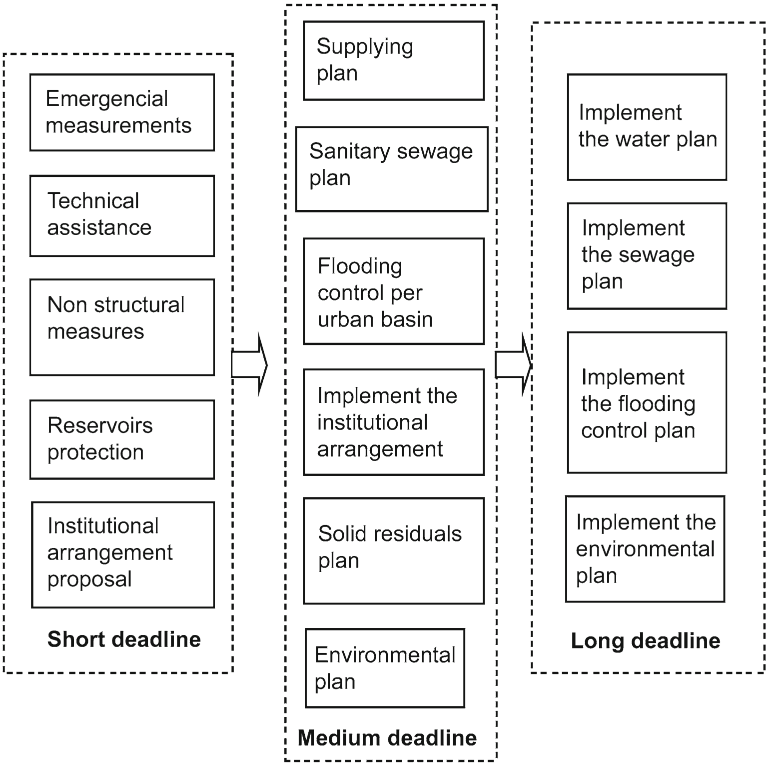

Fig. 7.9 Action plan

3. Control of the flood management per urban basin: the plan should develop a flood control scheme per urban basin, also taking into consideration the protection of the watersheds, the generation of solid waste and the interconnection of the networks.
4. Implement institutional agreements: in this phase, the institutional agreements planned in the previous phase should be implemented in order to allow for the development of the planning within a sustainable municipal planning structure.
5. Implement the Solid Waste Plan: the implementation of the solid waste plan can start in the previous phase, as a pilot plan, but in this phase it should cover the entire area. This plan should include an institutional reform.
6. Environmental Plan: development of a plan for the basin and a strategic plan for the environmental compensation which encompasses all the action of the Environmental Sanitation Plan. This plan should determine environmental goals for the area.

Development of the plan should specify the interface areas of the plans and their approaches. It is important that the plan does not become fragmented into several plans, and is developed within a same structure.

Long Term: this phase represents the implementation stem of the measures, together with the projects foreseen in the Plans.

Conclusion

The management of urban waters is currently done in a very fragmented way, leading to significant problems of impacts and harmful consequences to urban sustainability.

The main aspects which lead to urbanization of cities under development were analyzed, as for example Brazil and the characteristics of income conditions which lead to the planning of a formal city and a city developed in an illegal form without infrastructure. One can observe that, with economic growth, illegal cities in general, decrease, but it is up to government to induce the development of a sustainable city which reduces these unfavorable conditions at the same time in which it creates the adequate life conditions for the urban population.

The world's population is becoming increasingly urban and the tendency is that, by the middle of this century, 70 % of the population will be living in cities. In the way cities are being planned and developed, this process can become disastrous, because we will lack natural resources, which will be destroyed by urban development itself. This occurs because the services which the cities should be able to supply in the different spheres do not possess a connection among themselves. Imagine a sick patient in the ICU of a hospital where the doctor who attend to that patient, of different medical specialties, do not communicate among themselves and are not interested in his survival. The city is currently in the ICU, and nobody is interested in the final result of the combination of services.

The integrated management of the city and of urban waters should seek to plan and operate the city's services in an integrated way. This is a great challenge in an extremely corporative sector that sees very little outside of its own specific activity. For example, how many sanitation companies do you know, that measure the quality of a river in order to analyze the effective result of the sewage treatment or even the change in water quality which it removes from watersheds? How many service companies have society goals? Most of them work with kilometers of network and investments, which are not society goals.

Integrated planning of a city's sanitation is essential within these ideas, as foreseen in the Sanitation Law in Brazil. The big problem will be to change this into a reality, in a world of professionals with a limited idea of what sanitation is.

This article presented the relationships between urbanization and the services related to water resources, characterizing the principles of integrated management and the action plans which can be developed in the city in an attempt at sustainability.

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Chapter 8
Education for Sustainability of Water Resources

Myriam Krasilchik, Luiz Marcelo de Carvalho, and Rosana Louro Ferreira Silva

Abstract In this paper we present an analysis of fundamental aspects to contextualize the environmental education as an essential component to discuss water resources sustainability. First, we point out historical factors concerning the establishment of Environmental Education in Brazil, underscoring water resources in projects, programs and public policies. After that, we discuss social and institutional factors associated with water resources and their interface with environmental education, in reference to the National Policy and Plan for Water Resources (Política e Plano Nacional dos Recursos Hídricos), the National Policy for Environmental Education (Política Nacional de Educação Ambiental) and the National Curricular Guidelines (Parâmetros Curriculares Nacionais). Within the academic context, we present quantitative and qualitative data from research in the field of environmental education, particularly research projects that focus on water resources, indicating their trends and perspectives in knowledge production on a national level. Finally, we suggest perspectives for a critical environmental education and highlight ways under which the approach underlying pedagogical practices and textbooks can be identified, mainly concerning the core concept of river basins that allows a systemic analysis of problems associated with water resources. These suggestions are based on the premises that environmental education may be an important tool to empower participatory management and knowledge exchange, and that this systemic and interdisciplinary approach should be a consistent component of pre-service and in-service teacher education programs.

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Introduction

The UN's General Assembly declared in December 2002, that the period of 2005–2014 should be considered the Decade of Education for a Sustainable Development, under a global coordination and implementation by UNESCO.

Among the objectives of the program of the Decade, are the reorientation and the revision of the educational programs, from preschool to university, including the development of knowledge, abilities and values regarding sustainability; considered important for current and future societies.

This same document considers one of the challenges of the Decade, or EE as the educational component focused on restoration and environmental protection is internationally referred be going beyond environmental education.

Although the proposition for a sustainable development might be seen as pertinent, as per certain aspects and context according to Sauvé (2005), it is no longer possible to not consider the utilitarian concept of education and how it represents the resources of the environment, encompassed within this model. For some educators, UNESCO'S proposal is throwing out a social and political perspective which is already well set up within the progress of environmental education (González-Gaudiano 2007). Considerations like these reinforce our understanding that the analysis of these occasional transitions cannot be made without taking into consideration the history of EE in Brazil in the last 50 years, which was a crucial period of environmental crises.

Without ignoring the fundamental role which environmental movement has historically developed and continues to develop with regards to environmental education, the first specific programs of activities destined to protect the environment, come from initiatives of teachers of elementary and middle schools, in some cases, assisted by university professors. As an example, in the 1950s students and teachers of a High School had the objective of discussing and forbidding pollution caused by the dumping of fermented sugarcane bagasse being thrown into the Piracicaba river by alcohol and sugar mills.

In Rio de Janeiro, the preoccupation with the environmental impacts of the urbanization process could already be noticed in a book published in 1958 when the author wrote "beaches where pioneer vegetation should exist being substituted by walls of stone or by the proliferation of vegetation made up of grass and plants substituting native plants" (Santos 1958).

In the decade of the sixties, reflecting the world's situation mid Cold War, projects were developed for schools with the objective of updating contents and graduating scientists, making a considerable contribution towards the teaching of science. In these projects, aspects related to the environmental impacts and their consequences were greatly focused upon. The scientific societies, as for example the American

Institute of Biological Sciences, with the support of the government, produced the so called first generation of projects like the Biological Science Curriculum Study (BSCS). This project was originally produced in the USA, who already focused on the reciprocal relationship between organisms and the environment analyzing what man has done with and to the environment, creating the need for conservation and introducing ecology into the curriculum.

The addition of Ecology as a subject in universities, greatly contributed towards the expansion of the EE programs. As a theme of the Biology curriculum of high schools, it exemplifies the scientific progress which enabled the development of more precise methods for measuring the physical environment, for characterizing organisms physiologically and genetically, for creating models to simulate ecological situations, and to perform studies on relationships of organisms of an ecosystem, among others.

Since that time, one did not intend to restrict environmental issues to biologists, for they could not be confined to one subject alone, and should percolate the entire curriculum and consider the consequences of environmental changed caused or not by humans. The environmental crises of the 1970s, which involved political, social and economic aspects, demolished the belief that science was the panacea to solve the problems of humanity, and influenced the educational programs on environmental education. By the beginning of the 1980s the topic permeated lower schools and Teacher Training Centers, in the area of Science, were created in São Paulo, Rio de Janeiro, Salvador, Belo Horizonte and Porto Alegre.

In this phase, the Teacher Training Center of São Paulo prepared a Project for the teaching of Science in the fifth to eighth grade,[1] in which aside from dealing with issues related to ecological and environmental problems (i.e. trash, water pollution, energy), it also suggested modifications to the pedagogical strategies recommending games, debates, lab experiences, etc. to lead students away from being passive and memorizing content, which is common in science courses. Several of these activities are used up until today by teachers and authors of academic books.

From this context, and influenced by several international movements such as UN conferences like the "First UN Conference on Environment and Development" held in Stockholm, Sweden, in 1972; the Belgrade Congress held in 1975, in which its final document determines the goals and principles of EE; the Ybilisi-Georgia Conference held in 1977, which established the guiding principles of EE and reinforces its interdisciplinary nature, and defines it as critical, ethical and transforming; the second UN conference on Environment and Human Development, held in Rio de Janeiro in 1992; and through initiatives of the Ministry of the Environment and the Ministry of Education among other institutions, that several strands of work have been opened, catalyzed by public policies and initiatives from schools, the media and organizations.

At the same time, universities started to perform researches, within their post-graduation courses, to analyze objectives, conceptions, values and meanings of Environmental Education, not only within the school, but extracurricular as well. Table 8.1 below, contextualizes evolution in various phases. It is important to observe

[1] "Ciências Ambientais para o primeiro grau", of 1982, under the responsibility of SEPS/PREMEN/FENAME.

Table 8.1 Main aspects of the evolution of environmental education in Brazil

Period	1950–1970	1970–1990	1990–…
World situation	Cold War	Social and economic crisis	Technologic competition.
			Globalization.
Brazilian situation	Industrialization	Dictatorship	Democratization
Education objectives	Formation of scientists	Formation of working citizens	Formation of engaged citizens
Environmental Education Objectives	Ecology	Nature conservation.	Sustainable development.
		Sustainable development.	Sustainable societies.
Main methodology	Transmission of knowledge	Games, debates, laboratory	Government projects.
			Study of the environment acting in the community.
Social actors	Environmentalists and teachers	Environmentalists and teachers	Environmentalists, teachers, entrepreneurs, midia, etc.
Conferences and documents	Silent Spring—Rachel Carson	Tbilize Belgrade	Rio 92
	Rome Club	ONU 1971	Rio + 10
			Environment Education Conferences I, II, III and IV
Public policies	Support to projects of Centers of Science by MEC	Sparse in some environment legislation and presence in the 1988 Constitution	Laws, resolutions, and proper curricular proposals
Main Environment Education conception	Conservative	Pragmatic	Pragmatic and critical
Research	Projects evaluation	Projects evaluation, research	Post-graduation in the universities

that in this summary only the predominant trends were included, and that in many cases they overlap and coexist depending on the policies, values and current conditions.

Today it is possible to identify an ample scope of initiatives that reflect the interest and the worries causes by the current environmental situation, and the role of education in this needed transformation. The governmental agencies try, at several levels, to implement public policies by means of mechanisms of control, publications, and continuous programs for qualification of teachers and community leaders. Without a doubt, research today plays an important role in analyzing the causes and consequences of environmental problems, and education is concerned in preparing well informed citizens who will take action towards seeking change.

It is interesting to observe, however, that some issues have occupied a place of prominence in the projects and environmental education programs, and among those, undoubtedly, the so called water resources. This fact which can be observed in our country as well as in foreign countries can without a doubt be explained due to the significance of this element of nature in the processes of maintaining life on Planet Earth, and probably because of the levels of impacts in the bodies of water caused by human activities as well. This concern, which is reflected in the proposals for environmental education in our country, can possibly explain the attempts, in terms of public policies, of providing an integrated approach to the several and complex dimensions involved in the management of the issue called water.

Social and Institutional Aspects of Water Resources and Their Interface with Environmental Education

The process of institutionalization of the water resource systems is based on historic background of the legislation, which reached its peak with the passing of Law number 9433/97, dealing with the National Policy of Water Resources, and, in accordance with the discussions held in several international conferences about the subject, adopted an integrated and participatory management system of the waters.

Supplement to this policy, in 2006 the federal government proposed to strengthen it by means of a National Plan of Water Resources, aiming at improving the integrated management system in the country. Among the critical issues and challenges, the policy highlights that the consolidation of a participative management requires a systematic process of education and cooperation among the agents and the public and private actors, as well as dedicating effort towards the qualification of the participants within the system, including the qualification of new professional profiles and consequently the adaptation of the curriculum (Brasil 2006).

However, the connection with education is presented in quite an incipient way in this plan. Upon analyzing the coordination of the integration of Water Resource Policy with other correlated public policies, the document does not mention the public policies related to education, even though it includes other areas of extreme relevance such as health, sanitation and energy.

Although even without including it in this coordination, the plan has one of its subprograms (that is part of the IV Program, Technological Development, Qualification, Communication and Spreading of Information on Integrated Management of Water Resources) that deals with “Qualification and Education especially Environmental, for Intergraded Management of Water Resources” and has as its main scope, the perspective of qualifying multiple agents, for different target audiences, so that the National Policy of Water Resources is spread throughout the country. However, it emphasizes that, with regards to environmental education, its development will remain restricted to themes and methodology which concern GIRH, maintaining execution decentralized from the states and the water basins, taking into consideration the basic guidelines of Agenda 21, of the Environmental Education for Sustainable Societies Treaty and the Carta da Terra (Brasil 2006).

This way, despite not having a partnership with public policies, and without an implementation strategy, EE is still considered to be a tool for the strengthening of a participative management of water resources.

With a participative management qualification in mind, the Environmental Education for Sustainable Societies of Global Responsibility Treaty, signed during the Rio-92, highlights the permanent nature of environmental education in the goal towards building socially fair and ecologically sustainable societies. Several principles of the treaty supply elements that lead towards a collective participation in the management processes, such as those that indicate that environmental education should be planned in order to qualify people to solve conflicts in a fair and human way, as well as promoting cooperation and dialogue among individuals and institutions, with the objective of creating new ways of life based on meeting everyone's basic needs.

Specifically about the curriculum, the National Curricular Parameters, edited by MEC as of 1996, refer to the environmental issue as a transversal theme. In one of the chapters, called "The Cyclical Characteristic of Nature", water is used as an important axis to study the idea of cycle. Some of the topics proposed, address the understanding of the physical and socioeconomic factors; the understanding of the concept of watershed, identifying the school's location within that basin; the issue of water and its history; knowledge about oceans; the use of water in different cultures and the waste of water by industrial societies. This proposal has the objective of supplying subsidies to students to advocate changes in the management of this natural resource, guiding towards sustainability and the development of coherent personal attitudes (Brasil 1998).

The National Policy of Environmental Education, established by Law number 9795/99 considers environmental education to be "a process in which the individual and the group builds social values, knowledge, abilities, attitudes and skills aimed towards the conservation of the environment and of common use assets, essential to a healthy quality of life and to sustainability". This concept of environment as being an asset or a resource despite not being consensual among environmental educators is similar to what is adopted by the National Policy on Water resources, and reflects the understanding of the Brazilian Constitution of 1988.

It is important to highlight that the understanding of watersheds and watershed committees, are crucial to the policies and actions which are currently being implemented in Brazil, and particularly in the State of São Paulo.

As an example of the importance that understanding the concept of river basin represents to EE, the São Paulo Network of Environmental Education, which started as of the Rio-92 conference, is composed of people and institutions who develop EE activities and who are considered as links of the network. The links are organized according to river basins or UGRHIs, Units of Water Resource Management. REPEA has the objective of coordinating, in other words, of working together in order to strengthen Environmental Education in the State of São Paulo.

As it was emphasized, the basins are stages of natural and social processes, seeing that, although they are characterized by physical factors, they are influenced by human occupation and by the actions of several social groups who live there.

However, upon analyzing continued education and all the support material, one can observe that the concept of watershed is still very far from professors and academic books. The issue of water is frequently dealt with through the behavioral aspect related to economy and to the rational use in homes, without a greater context of understanding of the social and historical relationships which occur within the basin where they are found (Otalara 2008). It is important that the qualification processes of environmental education, emphasizes that there are no isolated problems; they are all part of a network that constitute a chain of successive events. Upon analyzing projects for environmental education under the perspective of management of water resources, Bustos (2003) highlighted that, according to the current legislation, the search for solutions is no longer the exclusive responsibility of experts, it now encompasses the participation of citizens, the integration of the socio-environmental problems and the qualification of partnerships which are crucial to the participatory management process. In this aspect, environmental education takes on an irreplaceable nature.

For any environmental education Project, the diagnosis of the local situation, including social, cultural, natural and historical aspects, among others, becomes essential, seeing that there are no models of EE which adapt to all situations. The inclusion of the topics water resources and environmental education in laws, decrees and curricular programs do not in itself guarantee an effective coordination in schools and within the communities. Considering the public nature and the equal rights over natural assets granted by the constitution, water, similar to the majority of the issues related to the environments, is liable to conflicts. An Environmental Education, in its critical perspective, should provide qualification elements for a person to not only be able to identify the extent of the conflicting relationships, but also to be able to have an opinion about them (Carvalho 2004).

These conflicts are reflected in the current water crises, which, as indicated by Tundisi (2008), has local, regional, continental and planetary dimensions, contributing towards the increase and exacerbation of the contamination of sources; altering the sources of water resources—watersheds—with scarcity and decrease of availability; the increase of human population's vulnerability due to contamination and the difficulty to access quality water; and the interferences to public human health, with the deterioration of quality of life and of the social and economic development. The author emphasized the central focus of water resources with regards to energy, production of food, sustainability of biodiversity and global changes. We further emphasize the historical importance of the issue of water resources not only in defining public policies related to environmental issues but also for environmental education.

Environmental Education and Water Resources: The Context of the Research

Actually, issues related to water, water resources, river basins or watersheds have been the most focused upon by historic preservationist and conservationist movements, being, even in current times, the central focus of discussions or proposals of policies related to environmental protection (Millenium Ecosystem Assessment 2005, Sutherland et al. 2006, 2009).

The same process can also be observed when dealing with environmental education research, in other words, researches which aim at analyzing and understanding environmental education processes. Several researches discuss these processes related to water resource, as can be seen through a simple search through CAPES' Dissertation and Thesis Files. By searching the key words "Environmental Education" one will find over 2600 Master thesis and PhD dissertations. The context of the research of environmental education has shown an amazing scenario in some aspects. Some authors have brought our attention to the staggering growth in this area. It is interesting to observe that, although the so called greening process of society is fairly recent, with the development of practices within the so called environmental education, the work we recently performed aiming at defining a panorama of this production in our country, indicating certain tendencies in the area and identifying some of their dilemmas, are according to our evaluation not at all different from those identified in our research on education in our country (Carvalho et al. 2009). Anyhow, it becomes quite evident, in a numerical point of view, the staggering expansion based on the number of dissertations and thesis related to environmental education developed in the different programs of the national system of post-graduation (Fracalanza 2004; Fracalanza et al. 2005).

A search on the crossing of the words "water" and "environmental education" identified 353 documents, which corresponds to 13.5 % of all thesis and dissertations written, related to environmental education, in the several post-graduation programs of the country. Crossing the word with "water resources", we reach a total of 135 documents, which represents 5.19 % of the total of thesis and dissertations. These numbers are significant, at least in a numerical point of view, when one considers the diversity of the themes within environmental issues. Another quite interesting data is that today, there are 103 research groups registered in the Directory of Research groups of CNPq, that in some way incorporate the subject "environmental education" and water within the lines of their research. The efforts of the academic community are evident, in the sense of strengthening the field of research in environmental education and in spreading the knowledge acquired through researches. Thanks to the coordination of researchers, it was possible to put together a study group in 2003, together with the National Association of Post-Graduation in Research and Education (ANPED)—an association acknowledged as being a representation of the area not only by the institutions who work with research in environmental education in Brazil, but also by researchers in the field of education. In 2005, the study group became a work force, which is today known as GT-22 "Environmental Education" together with ANPED that in their annual meetings, gather several research groups of environmental education to discuss the works of the area and the paths for post-graduation and for research in education in the country. It is also worth mentioning the creation of the GT of Environmental Education in the National Association of Post Graduate and Research in Environment and Society (ANPPAS) who, similarly, deal with Environmental Education research. In several scientific meetings held in our country, there are several works done on environmental education, and in several of these events, work groups are organized to discuss the tendencies and the perspectives on several dimensions of environmental education. With regards to scientific events, it is worth highlighting the joint effort of several research groups linked to three public universities of the State of São Paulo (UNESP/Rio Claro, UFSCar, USP/Ribeirão Preto) in proposing and organizing the Meetings on Environmental Education Research (EPEA), previously mentioned, which has been occurring since 2001 and had its fifth meeting in the end of October 2009.

With the objective of seeking a closer interaction with the researches on environmental education that has dealt specifically with the issue of water resources, we have tried to identify among the works presented in the four EPEA editions, those with specific characteristics. The idea behind this analysis is not to determine a panorama which indicates the representation of the tendencies of the works in the area of Environmental Education that deal with the issue of water resources or water, but to indicate paths and perspectives for the production of knowledge in these areas at a national scope. This way, despite recognizing the limits that an analysis of texts published in the annals of a specific event can bring to our discussion, we believe that such source can allow us to determine tendencies and perspectives, bearing in mind its national outreach, the specificities with regards to the objectives of spreading and discussing the research on environmental education, and the number of works which have been forwarded for widespread and discussion in the different editions of the event.

Based on the data systematized by Rink (2009) in her PhD dissertation called "The analysis of academic production presented in Meetings of Environmental Education Research (EPEA)" one can obtain the first information on the group of work on environmental education research with water resources, published in the Annals of EPEA.

While classifying the analyzed texts based on the theme or on the main area of knowledge of the articles, Rink (2009) identified 23 texts (7.6% of the total of works presented in the four EPEAS already held) which have the issue of water resources as one of their central themes. This number is only inferior to the number of works which focused on the area of Ecology (in a more ample approach). This data is evidence that confirms the previously enunciated fact that water resources are one of the issues which has gained special attention from researchers. The analysis performed by Rink (2009) revealed other interesting aspects. Among the works which deal with the themes related to water, one can observe certain preponderance of the reports which analyze and discuss educational works in school contexts, in particular those related to the final grades of Middle school. Another observation of the author is that the majority of the works of the referred theme is focused on attempts of identifying conceptions, representations, perceptions and concepts of the public involved in the research about water resources (Rink 2009). The same has also been observed with regards to other issues approached in the research presented at EPEA, a tendency called by Carvalho and Schmidt (2008) as the search of the meanings given to environmental education.

It is also worth mentioning that one has observed, in the works published by the Annals of EPEA, that many who analyze and assess a specific Project on environmental education for Lower and Middle schools have water resources as their central theme. The same can be said about the works that analyze the pedagogical potential of the projects focused on environmental education (Rink 2009).

Perspectives of Environmental Education, Critical for Water Resources

It is important that the professor or any other actor, who seeks to work with participatory management of water resources using environmental education as an element for its strengthening, is able to identify what is the predominant conception of the proposed activities. With the objective of assisting teachers in analyzing the action proposals in environmental education, maintaining a critical perspective, we present a classification into three categories of environmental education (Silva 2007) conservative, pragmatic and critical, summarized in Table 8.2.

Table 8.2 Conceptions of environmental education (adapted from Silva 2007)

Conservative	Pragmatic	Critical
• Dichotomy human being-environment.	• Anthropocentrism (human being as the center of everything).	• Human being belongs to a network of social, natural and cultural relationships and lives in interaction.
• Human being as a destructive dimension.	• Fatalist perspective—need to protect the environment (in order to survive).	• Relation with environment is historically determined.
• Contemplative activities.	• Action-reaction law (Nature revengeful).	• Proposition of activities obligatorily interdisciplinary.
• Return to the primitive Nature.	• “Technical/instrumental” activities without reflection propositions (e.g. separate recycling goods or get bonuses for it).	• Solution of problems as themes generators.
• Human being is part of Nature in its biological dimension.	• Solution of environmental problems as an end activity.	• Local/regional environmental potentialities are explored.
• Contemplative activities.	• Propositions for individual activities.	• Recognition of conflicts.
• Commemorative dates and other punctual activities.	• Proposition of models of environmental behavior.	• Emphasis on the collective participation.
• External activities of “contact with Nature” as an end in itself.		• Questions of equality of access to the natural resources and unequal distribution of environmental risks are discussed.

This categorization becomes important since there is no consensus or homogeneity of the practices and the academic materials which stand for Environmental Education. Therefore, one attempts to allow educators or other social actors related to the environment, to be capable of identifying the concepts which they wish to explore in their practices, as well as having the elements to analyze the academic material and projects and guide their decisions about the use and the means of using and the ways of appropriation and re-signification in different contexts.

Among the different aspect revealed by the research in this field, and the values considered significant, we have briefly indicated those which to us seem most relevant to the development of educational works in the field of environment within a critical perspective.

The observed tendency of proposing watersheds as a reference for the analysis of aspects related to water or water resources. This perspective represents a significant progress, since it recommends a discussion of the problems related to water resources in a spatial scope, which is where degradation occurs. The regional outreach of this treatment emphasizes the need for an integration of the discussions on the different environmental issues, for example, the conservation of the land, and of the riparian forests, increasing the outreach of Environmental education programs. With more integrated analysis of these different issues, one can work in a more concrete way, on concepts considered difficult by teachers, especially when dealing with students from lower and middle school or with communities who have little experience in dealing with abstract concepts. As proposed by Bacci and Patacca (2008), to work within the context of watershed allows for coordination between the singular and the historical, creating opportunities for learning experiences.

To use the watershed as a unit of analysis also allows teachers to place students in direct contact with different social agents and different social sectors that are responsible for the management process of water resources. Experiences like these can assist those involved in the educational process to have a better dimension of the need for integrating efforts, so that the measures which are in fact effective in the process of mitigation of environmental impacts or which aim at finding a solution to problems related to preservation and conservation of waters can be implemented.

In addition, these experiences render valuable experiences in understanding the need for participation of the entire community in the transformation process we seek, contributing to avoid the approaches which focus on and reinforce changes of habits and on individual attitudes which currently are very present in the environmental education proposals.

The contact with different agents, with social sectors and with several community groups, leads us to consider another principle which can greatly benefit from a more systemic approach such as: the much needed dialogue among the knowledgeable in dealing with environmental issues. One example is the project "The building of a participatory process of education and change" developed in Espírito Santo do Turvo and Vera Cruz, in the State of São Paulo, by a team composed by professors from ESALQ, FSP, FE and the Agronomy Institute of Campinas (Krasilchik et al. 2006). For proposals where one attempts to have several groups involved and feeling like they participate in the process, it is necessary to grant recognition to the different specialists and to give them the necessary consideration in the game of knowledge and Power, present in our society. It is not about not taking into consideration the role of the scientific knowledge in these processes. It is in fact about preparing scientists who participate, to listen and dialogue, in order to consider the possibilities of different interpretations of the complex phenomena we deal with when working with environmental issues.

It is worth taking note on the frequent mentioning of the potentials and possibilities of the works which utilize the watershed as a unit of study open for the development of field activities. Although it is important to repeat our understanding that there are no prior research procedure considered adequate for environmental education, field works offer paths to alter or pedagogical practices not only when we find ourselves within school contexts, but also in other educational contexts.

Upon analyzing environmental education projects with water resources performed in the Upper Tietê River Basin, Bustos (2003) noted that the lack of effectiveness of the projects was due to the lack of coordination, integration, monitoring and continuity, focusing on the need for a systemic planning for such actions and the difficulty in working on a Project of integrated and participatory management.

The challenges of these paths become evident, especially when we analyze the background of our educational systems and the strength of recurring practices in their processes of dealing with the challenge. Each one of the previously mentioned items puts us in contact, for example, with one of the principles, taken on with the highest consensus when we deal with environmental education, regardless of its interdisciplinary perspective. The research texts presented at the EPEA and used as documents for this analysis, show the great difficulty in the approaches which require the integration of the different areas of knowledge. The can also clearly be seen in Rink's work (2009). The author brought to our attention, regarding researches held within the school context, that although they insist and emphasize on the interdisciplinary perspective, they end up being done involving one subject only. Many times the integration efforts manage to involve more than one area of knowledge, yet without actually achieving interdisciplinary characteristics.

There is no possibility of qualifying an educator for an interdisciplinary work if he does not possess practical experiences in formative spaces where he could experience the principles and interdisciplinary practices. Facing these challenges, requires a joint effort of all levels, spaces and qualification of key people who are dedicated to environmental education.

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Chapter 9
Ground Water: Strategic or Emergency Reserve

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Abstract Ground water in Brazil is progressively being exploited to supply cities and urban centers, as well as for industries, irrigation and tourism. It is estimated that there are 416 thousand wells in the country, with an annual increase of 10.8 thousand new wells being drilled, meeting the needs of 30–40 % of the population. This exploited volume is still small when compared to the potentials of their renewable reserves of 42,000 m^3 s^{-1}. Despite its considerable contribution to the social economic development of several regions of the country, and its ecological role in maintaining the base flow of water bodies, management of ground water is still incipient and does not reflect its current and strategic importance. The lack of public policies reflects the current lack of information regarding the total amount of water being used from aquifers, as well as the lack of knowledge regarding the risks of anthropogenic contamination to which they are subjected, and which affect water quality. The water matrix of the country does not contemplate this resource in a correct way, and therefore loses opportunities of using it efficiently. If water were used correctly, cost could be lowered regarding installation and operation of supply systems, in addition to protecting the water in issues related to climatic changes. Challenges for adequate managements include: (a) discipline of ground water use; (b) protection of aquifers and catchment with regards to anthropogenic contamination; and (c) establish technical solutions for an integrated and efficient use of surface and ground water.

Keywords Contamination • Ground water • Integrated use • Management of water resources • Overexploitation

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Introduction

Ground water is essential for human development. In Brazil, it plays an important role in public and private water supply, meeting the most varied needs for water in several cities and communities, as well as in autonomous systems in homes, industries, services, agricultural irrigation and pleasure. Least acknowledged, but equally important is its ecological role, essential for the maintenance of flora, fauna, landscaping and aesthetic purposes in surface bodies of water, since the perpetration of the majority of rivers, lakes and marshes is done through the discharge of aquifers, via the base flow. This same base flow is also important to assist in the dilution of sewages and avoid siltation of rivers caused by the accumulation of sediments and waste in the cities due to the loss of dragging capacity. Preliminary assessments indicate that aquifers supply water to 30–40 % of the country's population, especially in medium and small cities, but some capitals are also listed, like Natal, Fortaleza, Belém, Maceió, Recife, Porto Velho and São Paulo, where supply is partially done by ground water resource. In the State of São Paulo, 70 % of the urban centers are totally or partially supplied by ground water, including large cities such as Ribeirão Preto, Marília, Bauru and São José do Rio Preto. In the Northeastern semi-arid region, the rural communities have an important watershed in ground water, as does irrigation in the West of the Chapada do Apodi, between the states of Ceará and Rio Grande do Norte. What is also not commented upon is the fact that all mineral water is ground water—yet the opposite is not true. In addition, ground water is responsible for tourism by means of thermal or mineral water in cities like Caldas Novas in Goiás, Araxá and Poços de Caldas in Minas Gerais, Lindoia in São Paulo, aside from being responsible for the supply of the growing market for mineral and bottled water, marketing about US$ 450 million per year. Despite ground water demonstrating its importance in the water matrix, it is still not very exploited. Ground water potential is enormous, especially when one analyzes that, on a global scale, 98 % of fresh water and liquid water reserves are found in aquifers. This tremendous storage capacity and resistance to long periods of droughts, like the ones we currently have due to climatic changes, make ground water resources one of our greatest allies in reducing the water stress which populations have been facing and will continue to face.

Focused on the sustainable management of water resources, Law number 9433/97, of the National Policy on Water Resources, represented the legal framework of a new way of thinking the use of water resources, based on a sustainable vision, considering a decentralized administration and the participation of society. The creation of this law and the progress achieved from its implementation throughout the last 12 years were significant, and its importance has been reinforced by the growing attention society has been attributing to water resources. However, even though the vision of an integrated management of surface and ground water in water basins is made explicit in the law, the assessment of managers and even of users is that it is more of a competition over resources than actually integration. Thus, separately contemplating surface and ground water watersheds represents, aside from a simplification, a limitation in the effective solving of the problem society awaits an answer for (Zoby and Matos 2002). Ground water should not be seen, in this context, as an adjunct to the water supply of cities, communities and even businesses. It should in fact be considered an equally important alternative as a watershed and important in an economic point of view.

The objective of this article is to discuss these issues, showing the uses and potentials of ground water resources in the country, indicating alternatives for an integrated and optimized exploitation, benefitting the environment, society and economy.

Ground Water in Brazil

Renewable reserves of ground water in Brazil, in other words, their effective discharge, reach 42,289 $m^3 s^{-1}$ (1334 $km^2 a^{-1}$) and correspond to 24 % of the runoff of rivers in the country (average annual flow of 179,433 $m^3 s^{-1}$) and 49 % of the drought flow (considered as a drought flow with a 95 % permanence). Twenty seven of the main sedimentary aquifers alone, which occupy 32 % of the country, totalize 20,473 $m^3 s^{-1}$. This gigantic flow of water is distributed, in a simplified way, into two large groups: rock and sedimentary aquifers, and fractured rock aquifers (ANA 2005a, b; Hirata et al. 2006).

Sedimentary rock aquifers: sedimentary lands occupy about 4.13 million km^2, in other words, 48.5 % of the country, associating to the large sedimentary basins of the Proterozoic, Paleozoic, Proterozoic/Mesozoic and Paleozoic and the smaller Mesozoic and Cenozoic basins (Fig. 9.1, Table 9.1). In these lands, there are 27 systems of intergranular porosity aquifers and subordinately, karst and fractured, with an outcrop or recharge of 2.76 million km^2 (32 % of the country). The main Brazilian proterozoic sedimentary basin in the one of the São Francisco River, which comprises two important aquifer systems of regional dimensions, the Bambuí Aquifer System (Neoproterozoic) and the Urucuia-Areado Aquifer System (Cretaceous), totaling 175,000 km^2. The largest Brazilian basins are from the Paleozoic age and they are: Paraná Basin (Ordovician to Cretaceous, with 1 million km^2 on the Brazilian portion), with emphasis on the aquifer systems Bauru-Caiuá, Guarani, Tubarão, Ponta Grossa and Furnas; Parnaíba Basin (Silurian to Cretaceous, with 600,000 km^2), with emphasis on the aquifer systems of Itaperucu, Corda, Motuca, Poti-Piauí, Cabeças and Serra Grande; and Amazonas Basin (Ordoviciano and Terciary, with 1.3 million km^2), with the aquifer systems Boa Vista, Solimões and Alter do Chão (Fig. 9.1). The sedimentary basins of the Mesozoic have smaller dimensions than those of the Paleozoic, they are found mainly in the coastal regions or near them, and are in general very wide reaching millions of meters (Fig. 9.1).

Fractured Rock Aquifers: the Precambrian crystalline terrain, which behave as typical fractured aquifers, occupy an area of about 4.38 million km^2 (approximately 51.5 % of the country) and coincide, largely, with the Amazonas Craton and the Neoproterozoic fold belts, encompassing part of the basement of the

Fig. 9.1 Brazilian Cratons with folded bands and their boundaries

São Franciso Craton (Fig. 9.1, Table 9.2). The basement of the fold belts is predominantly constituted by metamorphic rocks (gneiss-migmatite, granite and granulite), with subordinate mafic and ultramafic rocks in addition to remnants of metavolcanosedimentary sequence of low to intermediate metamorphic levels. The fold are intruded by granite composed of metassedimentary rocks (terrigenous and carbonate) or metavolcanosedimentary (volcanic, terrigenous and cabonate) in varied metamorphic facies from green schist to amphibolite. Basalts and diabases from the Serra Geral Formation (Early Cretaceous) of the Paraná Basin constitute, together with the Precambrian rocks, the main fractured aquifers of the country.

In general, the aquifers of the country present excellent to good quality natural quality of its waters in almost all of its territory. The natural chemistry is basically controlled by the rocks and sediments that compose the aquifer and by the climate

Table 9.1 General characterization and productivity of Brazilian sedimentary aquifers (Hirata et al. 2006)

General characterization				Well production							
				Free aquifer				Confined aquifer			
Basin	Aquifer system	Type of aquifer	Lithology	Depth (m)	Q ($m^3 h^{-1}$)	Q/d ($m^3 h^{-1} m^{-1}$)	P	Depth (m)	Q ($m^3 h^{-1}$)	Q/d ($m^3 h^{-1} m^{-1}$)	P
Amazonas	Boa Vista	Porous and free	Sand, lateritic concretions	33–40 (34)	19.8–40 (30)	2.41–8.89 (3.15)	9	–	–	–	–
	Solimões	Porous and free	Siltstone and sandstone banks	38–62 (45)	10.2–36.7 (24.5)	0.97–5.22 (1.63)	36	–	–	–	–
	Alter do Chão	Porous and free	Clay and siltstone sandstones	85–189 (140)	9.4–68.0 (26.4)	0.35–2.26 (0.94)	145	–	–	–	–
Parecis	Parecis	Porous and free	Thin to medium sandstones conglomerate levels and siltstone lenses	100–112 (104)	72.0–283.0 (128.4)	5.76–15.36 (9.1)	8	–	–	–	–
Mesozoic/ Cenozoic	Barreiras	Porous, free and confined	Lime-clay sandstone and siltstone	20–51 (33)	4.0–18.0 (9.3)	0.31–4.83 (2.11)	140	37–66 (50)	2.6–10.6 (5.0)	0.16–1.35 (0.56)	167
	Beberibe	Porous, free and confined	Sandstone with siltstone intercalated	162–220 (200)	23.3–36.8 (26.0)	0.96–1.42 (1.10)	4	181–302 (250)	31.7–113.1 (72.0)	1.36–3.87 (2.59)	31
	Jandaira	Karstic fractured	Calcareous with siltstone, mudstone, limonite and calcareous sandstone intercalated	72–120 (100)	2.2–7.2 (4.5)	0.07–2.46 (0.29)	180	–	–	–	–
	Açu	Porous and confined	Thin and lime-clayey sandstone and levels of siltstone	–	–	–	–	59–535 (289)	6.4–32.2 (11.0)	0.65–4.78 (1.24)	16
	Marizal	Porous, free and confined	Coarse to conglomeratic sandstone with clay and calcareous levels	98–150 (118)	6.8–22.6 (12.7)	0.53–3.27 (1.35)	43	96–178 (142)	7.4–21.2 (13.5)	0.52–2.78 (0.95)	42
	São Sebastião	Porous, free and confined	Medium to coarse sandstone with siltstone and conglomerate mudstone levels	83–152 (119)	10.0–26.8 (16.5)	0.46–3.72 (2.06)	59	106–203 (164)	13.6–44.0 (24.0)	0.62–2.95 (1.38)	109
	Inajá	Porous, free and confined	Thin to medium sandstone with siltstone and clay levels	83–136 (118)	2.1–4.0 (3.3)	0.13–0.35 (0.24)	30	157–227 (187)	7.1–15.8 (10.2)	0.26–1.47 (0.77)	7

(continued)

Table 9.1 (continued)

General characterization				Well production							
				Free aquifer				Confined aquifer			
Basin	Aquifer system	Type of aquifer	Lithology	Depth (m)	Q ($m^3 h^{-1}$)	Q/d ($m^3 h^{-1} m^{-1}$)	P	Depth (m)	Q ($m^3 h^{-1}$)	Q/d ($m^3 h^{-1} m^{-1}$)	P
	Tacaratu	Porous and free	Thin to coarse sandstone with clay conglomerate levels	50–134 (73)	2.5–7.0 (5.0)	0.21–0.62 (0.47)	27	–	–	–	–
	Missão Velha	Porous and confined	Thin to coarse sandstone	76–83 (80)	4.2–8.6 (5.1)	0.43–0.85 (0.57)	3	53–84 (73)	4.1–19.0 (12.0)	0.29–2.57 (1.38)	15
	São Paulo	Porous, semi-confined	Sandstones, conglomerates, silty	100–175 (134)	5.8–26.4 (13.0)	0.18–1.76 (0.5)	165	–	–	–	–
	Taubaté	Porous, semi-confined	sandstones, conglomerates, silty	124–175 (150)	16.1–58.0 (30.0)	0.59–6.00 (2.1)	111	–	–	–	–
Paraná	Bauru	Porous and free	Thin to medium sandstone with silt intercalated	101–160 (140)	8.0–27.0 (14.4)	0.22–0.96 (0.43)	119	–	–	–	–
	Guarani	Porous, free and confined	Thin to medium sandstone	85–136 (103)	5.4–18.7 (10.2)	0.25–0.99 (0.49)	87	111–242 (154)	18.4–60.0 (35.7)	0.87–2.91 (1.82)	69
	Tubarão[1]	Porous, free and semi-confined	Thin to medium sandstone, diamictite, varvite	117–201 (151)	3.0–13.2 (6.8)	0.06–0.31 (0.12)	831	–	–	–	–
	Ponta Grossa	Porous and free	Clay with thin sandstone intercalated	118–192 (135)	1.2–6.0 (2.4)	0.02–0.12 (0.06)	9	–	–	–	–
	Furnas	Porous, free and semi confined	Medium to coarse sandstone	85–150 (115)	9.3–27.0 (11.6)	0.54–1.94 (1.20)	21	135–265 (175)	12.0–23.4 (15.4)	0.73–1.22 (0.94)	6

Parnaíba	Itapecuru	Porous and free	Thin to coarse sandstone, with mudstone levels	60–100 (79)	5.1–16.0 (9.1)	0.25–2.35 (1.03)	116	–	–	–	–
	Corda	Porous, free and confined	Medium to conglomeratic sandstone	72–112 (84)	4.0–18.0 (8.0)	0.40–1.87 (1.07)	35	147–250 (170)	7.2–20.0 (12.0)	0.29–1.14 (0.47)	47
	Motuca	Porous and free	Thin to medium sandstone	63–122 (80)	3.6–11.8 (6.1)	0.49–2.91 (1.90)	22	–	–	–	–
	Poti-Piauí	Porous, free and confined	Thin to medium sandstone with mudstone and limonite levels	93–157 (122)	6.0–18.0 (10.0)	0.34–1.46 (0.59)	49	111–346 (159)	13.4–40.3 (31.5)	0.92–2.91 (1.12)	10
	Cabeças	Porous, free and confined	Thin to coarse sandstone with mudstone levels	79–130 (100)	4.0–13.1 (6.0)	0.49–2.16 (1.00)	87	153–399 (233)	8.3–53.8 (26.4)	1.01–10.08 (4.37)	34
	Serra Grande	Porous, free and confined	Thin to medium sandstone with conglomeratic levels	107–200 (170)	2.0–6.0 (3.2)	0.06–0.33 (0.13)	111	120–180 (150)	5.9–21.0 (9.8)	0.63–2.42 (1.29)	111
	Urucuia-Areado	Porous, free and confined	Thin to medium sandstone with siltstone and conglomerate levels	50–117 (86)	5.5–14.7 (7.8)	0.19–1.15 (0.53)	28	–	–	–	–
São Francisco	Bambuí	Karstic, fractured	Metacalcareous, marl, metalimonite and meta-mudstone	60–100 (80)	3.3–15.7 (8.8)	0.10–3.17 (0.51)	159	–	–	–	–

The values of depth of Wells (Prof), flow (Q) and specific flow (Q/d) represent the percentile (25 and 75 %) of the average. P=number of wells consulted

Table 9.2 Pre-cambrian and volcanic fractured aquifer systems of the Eocretaceous (Hirata et al. 2006)

			Percentage and median								
			25 %	50 %	75 %	25 %	50 %	75 %	25 %	50 %	75 %
Geological unit	State, region or aquifer system	Wells	Depth (m)			Vazão ($m^3 h^{-1}$)			Specific vazão ($m^3 h m^{-1}$)		
Folding region and portions of the São Francisco craton	Northeast region	8329	48	59	70	0.8	2.1	5.1	0.03	0.10	0.38
	Minas Gerais State	128	–	–	–	1.1	2.8	5.0	0.03	0.13	0.35
	Rio de Janeiro State (2)	110	57	80	102	4.0	7.0	11.5	0.12	0.28	0.64
	São Paulo State	1201	110	150	198	2.6	6.0	12.1	0.03	0.09	0.30
	São Paulo—PC1	256	130	162	210	2.0	3.8	7.5	0.02	0.05	0.12
	São Paulo—PC2	633	108	150	200	2.7	6.0	12.6	0.03	0.09	0.27
	São Paulo—PC3	303	100	134	168	4.0	8.5	16.6	0.07	0.17	0.53
Parana water shed	Serra Geral—basalt	278	100	127	163	7.1	15.3	35.0	0.21	0.63	2.12
	Serra Geral—Diabase	49	90	121	157	1.8	5.5	11.0	0.02	0.13	0.40

in the area of recharge. The hydrogeological units of the North region, for example, where rain is abundant, show waters which are acidic, bicarbonate and low mineralized. Crystalline rocks are characterized by having calcic bicarbonate and calcic magnesium waters. Aquifers near coastal regions are, as opposed to inland waters, rich in chloride ions and sodium (Hirata et al. 2006).

Regionally, it is possible to identify problems associated to the excess of some ions, which could locally limit the use of water of the aquifers. The main chemical anomalies are (Zoby 2008):

1. In areas where limestone occur, local problems of high water hardness and/or total dissolved solids, are observed, as is the case of the aquifer systems of Bambuí and Jandaíra.
2. In aquifer systems located in the most confined parts of some sedimentary basins, under low circulation conditions, the growth of minerals in deep waters can cause restrictions to the use of water due to total salinity, as can be observed in the aquifer systems Guarani (Paraná and Rio Grande do Sul), Açu and Serra Grande.
3. Additionally, there are minerals, whose localized dissolution leads to waters with concentrations above potability standards; as is the case of iron in the aquifer systems Alter do Chão, Missão Velha and Barreiras and the case of fluoride in the aquifer systems Bambuí, Guarani and Serra Geral. Also known, is the case of the occurrence of elevated levels of chromium in the waters of the northeast of the State of São Paulo, in the Aquifer system Bauru-Caiuá.

In crystalline terrain, the problems of natural quality of ground water are concentrated in the Semi-Arid region of the Northeast (Zoby 2008) and refer to the high level of salinity. The use of desalination of water enables the use of these wells; however, reverse osmosis has been the most widely used process.

Exploitation of Ground Water Resources

An effective management of water resources in a watershed basically requires knowledge about water availability—both with regards to quality as well as with regards to quantity of the demand over water. In addition, it requires a database of users; of the aquifers vulnerability to pollution; and of the potential contamination sources that threaten the quality not only of the surface waters, but also ground water.

With regards to ground water, knowledge about water availability is limited at a national scale, and the few Regional studies are outdated (Zoby and Matos 2002).

The first hydrogeological map of the country was made by the National Department of Mineral Production (DNPM 1983). Rebouças (1988) synthesized the available information on the most important aquifers. Later, the National Water Agency (ANA 2005a, b) presented two publications with a synthesis of regional data on the quality of water, on reserves and productivity of the main aquifer systems of the country. More recently, in 2007, the Geological Service of Brazil (CPRM) presented a map of the hydrogeological domains and subdomains in a geographic system of information, on a scale 1:2.500.000.

With regards to regional studies, the most complete regional characterization of aquifers in Brazil was made in the Northeast, between 1965 and 1975, by the Superintendency for the Development of the Northeast (SUDENE), which is the "basic Hydrogeological Inventory of the Northeast". Also worth mentioning, within the national context, are the "Studies on the ground waters of the administrative regions of the State of São Paulo" performed by the Department of Water and Electric Energy, during the period of 1972 and 1983.

The chart above shows the lack of public policies for the management of ground water resources. The need for hydrogeological studies in the country also reflects the demographic densities and the levels of surface water scarcity with regards to the demands imposed by the population and by the economic activities. Therefore, the highest levels of information are concentrated within the metropolitan domains (Rebouças 1999).

This aspect becomes evident when one verifies the extensive quantities of studies on a local scale, mainly in some states of the Southeast and South regions. Although still very far from the real needs, the state environmental agencies have demanded investigations to characterize contamination of the soil and of ground water. In São Paulo for example, there are 2514 areas declared contaminated (CETESB 2009), many of which are also in the process of being remedied and a few even have already been finalized. Thus, even if there is a lack of regional public policies which would allow for the determination of priority areas for a detailed study, on the other hand, one can verify that individual cases of contamination are being studied, even if not in a systematic way throughout the country.

With regards to demands over ground water, there is yet uncertainty with regards to the number of wells existent in Brazil. Cardoso et al. (2008) performed, using several studies and data from water resources state management agencies and from the National Water Agency, analysis of each unit of the federation, estimating the existence of about 416 thousand wells drilled in Brazil since 1958, of which 63,000 would no longer be in use (approximately 15 % of the total). The current average of well drilled is of 10,800 per year.

For calculation of percentages and medians of the Semiarid Oriental Shield they were not considered the dry wells.

In the state of São Paulo, two areas had their exploitation restricted due to problems of intense use with no planning or due to overexploitation—the cities of Ribeirão Preto and of São José do Rio Preto. In these two localities, restrictive norms were established for the drilling of new wells or for the exploitation of ground water.

The lack of understanding of the hydrodynamic behavior of aquifers has above all complicated the understanding of the meaning of overexploitation. Studies performed in some location are restricted to describing the decrease of levels of water in a specific aquifer, not taking into consideration that this is an inherent characteristic to the use of ground water watershed. The real characterization of overexploitation should mandatorily take into consideration the assessment of the costs of ecological, social and economic impacts caused by this overexploitation, aside from their input and output balance of water from the aquifer.

With reference to the demand of water, it is also worth mentioning that the lack of knowledge about ground water's roll in public and private water supply creates an important problem. In the majority of cities the total amount of water that comes from wells exploited by private users, is unknown. Usually, estimates are underestimated and do not reflect the real dimension of the cities dependability on ground water resources.

A good example is that which occurs in the Upper Tietê Water Basin (BAT), where the metropolitan region of São Paulo is located. Supply by means of public network, with waters from surface origins that cover almost the total needs of the population, add up to 64 $m^3\ s^{-1}$, whereas the 10,000 wells in operation meet the needs of an additional 10 $m^3\ s^{-1}$ and, together cover the needs of the total demand of 74 $m^3\ s^{-1}$. The problem is that the facilities of the sanitation company do not possess the capacity of supplying additional water. If the private well (of which 70 % are illegal) stop their exploitation, whether due to its overexploitation or due to contamination, the public supply system would collapse; despite only supplying 15 % of the demand, there is no more water available unless a long term investment is made (Hirata et al. 2002). Another example is the paradox which occurs in the metropolitan region of Belém, located in a region with abundant water availability that has about 30 % of public water supply provided by ground water, aside from millions of private wells. Many of these private wells are poorly built, facilitating the occurrence of contamination, especially by domestic sewage. In fact, the lack of sewage collecting networks in this region results in the pollution of several of the rivers which cross the city, increasing the pressure for the use of ground water.

The country's current situation reveals that knowledge about hydrodynamic and about hydrochemistry of the aquifer systems is also extremely limited with regards to the monitoring systems available, contrary to what is observed with regards to surface waters, which have an extensive network of fluviometric monitoring, with about 5800 plants in operation. Only a few states have monitoring networks of quality and quantity, within their water resources and environmental management agencies. Some few examples of these networks are in operation in the states of São Paulo, Minas Gerais and Rio Grande do Norte and in the Federal District.

Aside from these agencies, the sanitation companies, which have ground water in the water matrix, also possess quality monitoring networks, even though these agencies are far more interested in verifying potability of the waters in their wells than they are in assessing the conditions of the aquifer as a whole.

São Paulo was the pioneer state in regional monitoring, having initiated its activities in 1990. Currently, the network has 180 public supply wells spread throughout the state, including the BAT, which are monitored biannually by means of 40 physical, chemical and microbiological characteristics, and even includes organic compounds (Dias et al. 2008). In the state of Minas Gerais, in the Verde Grande Basin, affluent of the São Francisco, a pilot water quality monitoring network was implemented, in 2004. In the Federal District, regional biannual quality monitoring was initiated in the second semester of 2006 in 150 operating wells by CAESB and includes 27 physical, chemical and bacteriologic characteristics. The monitoring of quantity started in 2007 and involves the measuring of the static level of 27 wells, some of which are exclusive for observation and others which are in use (Moraes et al. 2008). More recently, the Guarani Aquifer Project implemented a monitoring network in the four countries of its extension, nominating people in charge in each Brazilian state.

Through this report, it is obvious that the monitoring network does not meet the minimum requirements to understand the aquifers or its behavior throughout time and throughout use and the threat of contamination. In addition, it is worth mentioning that the monitoring wells are "blind", in other words they can monitor only one area of a few square meters located around it. Therefore, either we establish a strategy that focuses on monitoring networks, where they are most needed (with very clear objectives), or we increase the density of the wells and the frequency of monitoring samples. This lack of basic information about drilled wells results in the scarcity of trustworthy data on the actual water potential of the aquifer system and about the actual state of exploitation. Thus, we are lacking, for an effective planning of water management, the most basic information on hydrogeology that would allow for the making of decisions by competent water resources and health authorities.

The gap in the systematic knowledge of the situation of ground water in the country does not allow for the identification and the specification of the extension of the problems that affect the aquifers and its users. Anthropogenic contamination and the overexploitation of aquifers are occasionally identified by the territory, but without a systematization that would allow for the extrapolation of its real dimensions or for the identification of other areas of equal potential. It is true however that the problems are still few in contrast to the volumes and extension of aquifers, but it is also true that based on the information available, that these issues are rapidly increasing in number and in complexity, increasingly impacting underground watersheds.

There is no systematized assessment on contamination or on anthropogenic degradation of aquifers in the country. The state of São Paulo is one of the pioneers in these studies (Hirata et al. 1997), but it lacks a systemized update of their researches.

The knowledge available in the country indicated that the main contaminants are: nitrate, products derived from petroleum (especially gasoline and chlorinated solvents), heavy metals, viruses and bacteria. Nitrate is the individual contaminating substance most found in Brazilian aquifers.

In urban areas, it is a result of the lack of sanitary sewage systems, which in the country affects over 50 % of the population, and in areas where such sewage networks exists it is due to the lack of maintenance. Some studies have revealed that the loss of sewage of São Paulo networks has been above 40 %, with a significant volume recharging aquifers. Up until now, there are very few studies about the issue, aside from those described in the Barreiras Aquifer System for the cities of São Luís, Fortaleza, Belém and Natal (Zoby 2008); those for the cenozoic aquifers of the capital of São Paulo (Viviani et al. 2004); and some for the several cities of the interior of São Paulo (Cagnon and Hirata 2004), indicating that it is in fact an extensive problem throughout the country. In agricultural areas, nitrate originates from the excessive use of nitrogen fertilizers. Up until now, there are no studies about this in Brazil and the assessments are based on cases reported abroad.

Other contaminations of ground water by compounds in urban areas are the liquid fuels derived from petroleum. Based on the statistics of the state of São Paulo (CETESB 2009), the most common occasional contamination comes from service stations, by means of leakage of fuel from storage tanks, from underground pipes or from operation itself.

Heavy metals and chlorinated solvents are quite common products of industries, and are responsible for the largest and most complex contaminant plumes in aquifers. A recent study was requested by the Department of Water and Power to the Servmar Environmental Company, in the southeast region of the city of São Paulo. This study indicated that, in the area of Jurubatuba, an old industrial area, there are several plumes of contamination by halogenated solvents and that several of them overlap, even reaching the fractured aquifer underlying the sedimentary deposits with free phase chlorinated solvents denser than water. This area was the first in the country to suffer restriction in exploitation through a legal measure due to contamination. In this area, no new wells can be drilled and, where the contamination is detected, the well is sealed and the neighboring area is prohibited to drill new wells.

Heavy metals and several chlorinated solvents are also present in several aquifers due to the inadequate deposition of solid wastes in landfills. Based on statistics of other countries and on studies held in Brazil, it is believed that this activity might be the cause of the second greatest group of soil and aquifer contaminant in the country, proportionate to the number of activities in operation or abandoned.

The mining activity causes great alterations to the local hydrological cycle, reducing the vulnerability of aquifers due to the removal of the non-saturated area and the protective layers of the soil. One of the few areas where there is reasonable knowledge about this is in the State of Santa Catarina, where coal mining affects the quality of surface and ground water. In the state of Minas Gerais, studies about the hydraulic impacts of the mining of iron in rivers and in the aquifer itself are well conducted in several establishments, with a good monitoring network of aquifers by the companies responsible for extracting the mineral.

Additionally, saline intrusion is a problem that affects the aquifers in coastal areas, a result of an imbalance of ground water extraction close to coasts and the underground discharge, needed in order to avoid the invasion of salt water onto the continent. This problem has been identified in some urban aquifers, in coastal capitals, especially in the Northeast. Some examples can be found in the Barreiras Aquifer System, in the cities of São Luís, Maceió, Fortaleza and in areas of the state of Rio de Janeiro (Zoby 2008). The induction of low quality water by excessive pumping is also another issue that affects the aquifers, such as those observed in the Beberibe Aquifer in Recife, where the uncontrolled extraction is inducing the movement of saline waters from the Boa Viagem Aquifer in poorly build wells (Costa Filho et al. 1998). The same problem has also been observed in some aquifers located in urban areas in the state of São Paulo where the upper portion is contaminated by nitrate and the pumping of wells induce the plumes to its lower portions, compromising, in some cases, even the sources of mineral waters.

Lastly, the presence of bacteria and viruses is also very common in poorly built wells and/or in those that lack maintenance. The construction of wells out of the recommended standards by ABNT is common throughout the country, which increases the fact that the majority become vectors of aquifer contaminations due to the connection created between the surface and the saturated area, or also, between the shallow portions of the aquifers and the deeper portions. This issue is particularly worrisome in areas neighboring cities, where the lack of public water supply networks, results in supply wells being placed nearby cesspits, endangering the population.

Challenges for the Management of Ground Water Resources

The importance of ground water for the social and economic development of the population contrasts with the lack of knowledge about the potentiality and the stage of exploitation of the aquifers, resulting in great challenges for an adequate management of water.

A relevant aspect which needs to be considered is that the dynamics of ground water is different from that of surface waters. The river, from a water management point of view, is the “opposite” of an aquifer. The river has a low capacity for storing water, yet, on the other hand, can deliver a larger instantaneous flow than the aquifers. Additionally, aquifer exploitation is done through wells and springs, which usually have stable flows (which are not influenced by climatic seasonality), but are usually less than those compared to what has been observed in surface catchments. The use of this typical dynamics of both water manifestations is poorly used in the country. Even in cities that do make use of these two watersheds, there is no integrated planning that benefit of the advantages of each resource. In some cities, like Madrid (Spain), for example, the excess of surface water during rainy seasons helps recharge the aquifer after the critical period in which it was most used—during droughts, when the rivers were low in water and ground water supplied the city.

Likewise, exploitation of ground water is characterized by a lower initial financial investment and for allowing gradual solutions (one well after the other) in the implementation of large supply systems, allowing even, independent and atomized systems. Catchment of surface water however, need greater initial investments, and is not as flexible. Furthermore, pumping and electricity costs, render ground water uncompetitive in aquifers where transmissibility (result of the hydraulic conductivity and of the saturated width of the aquifer) is low or where the dynamic levels are deep or even where the demand is high and the productivity of the well is low.

Thus, it is crucial to rethink the water matrix; not only at a municipal level (involving the concessionaire and the local and municipal public authorities) but also at a water basin level (involving the basin committees) and train they based on this point of view, which would result in great economic, social and ecological benefits. Based on this, the National Water Agency is developing an Atlas of Urban Water Supply, which aims at optimizing the choice of the watershed, and proposes technical alternatives for the supply of water in the Brazilian cities by 2015.

The use of these concepts in public or private water supply has not yet been implemented in any part of the country; but a window of opportunity opens in several cities of Brazil. The concessionaires supply water to the population through the public network (both from surface and ground water origins). The population, with their tubular wells, is further supplied by ground water. Though not intentionally, concessionaires end up being benefitted by this additional source of water, for in many cases, it does not have the capacity of supplying the population's total demand. The real problem is that this is not a planned process and the knowledge about the real dependency on this additional supply, is frequently underestimated.

This lack of planning ends up bringing additional problems which could have been avoided, among them: contamination of waters of wells (whether due to poor catchment construction, or due to contamination in the catchment area of the well) and overexploitation, even affecting the wells of the concessionaries themselves.

The disciplining of the use of ground water through an effective program to license drilling and authorizations, together with billing for sewage services (of which concessionaires are entitled to and which could help pay off part of the investments in infrastructure), and an efficient social communication program aimed at users, could represent the cornerstone for an adequate exploitation of ground water resources. The concessionaires or the association of ground water users could assist the owner of the catchment in obtaining the maximized use of his well, thus reducing costs and environmental impacts, and consequently giving concessionaires a breather, who then would have less problems related to seasonal water demands, or even would be able to reduce their short and medium term investments in implementation of water treatment and reserve systems. At a second stage, municipal public authorities (whether associated or not to the basin committees) should seek to optimize the entire system in an integrated way.

Another important difference between the two water resources is the difficulty in the decontamination (remediation) of aquifers in comparison to surface water. Although the natural quality of ground water is excellent and meets potability requirements, the reduced speed of water circulation through the pores or through fractures, together with the complex geometry of the pores and its heterogeneity, makes decontamination for some types of compounds, such as free phase chlorinated solvents, practically impossible except by physically removing it from the aquifer. This characteristic, exemplifies why quality control programs should be focused upon prevention, rather than on the recovery of the aquifer.

Controlling use and soil occupation, by means of restrictions and monitoring of anthropic activities is one of the strategies for the protection of ground water, with two main objectives in mind (Foster et al. 2002). The first objective is the general protection of the aquifer, identifying areas most vulnerable to contamination, in order to carry out a regional control over the use of the soil in all its extension, especially on the outcrop areas. The second approach is on specific protection, focused on ground water catchment, which is usually a quite common tool used by concessionaires of water.

In Brazil, studies on the protection and the vulnerability of aquifers are still very limited (Zoby 2008). The state of São Paulo, as a pioneer, proposed technical criteria for the use of protection perimeters of wells (Hirata 1994; Iritani 1998). In some regions of the country which have considerable demands for water, studies to determine the vulnerability and/or the danger of contamination have been done, such as in the Northwestern portion of the metropolitan area of Belém, on the Serra Geral aquifer in Londrina and on the Beberibe Aquifer, in the North part of the Metropolitan Region of Recife; or even in the metropolitan regions of Campinas and São Paulo and in the cities of São José do Rio Preto, Itu and Sorocaba, in the State of São Paulo.

It is important to add that the protection of ground water depends entirely on anthropogenic activities; therefore, it can only be effective if it is implemented within the city's Master plan for land use.

More recently, ground water has been addressed, by means of Resolution 396/2008 approved in 2008 by the National Council of the Environments (CONAMA), which constitutes a new legal tool, encompassing all of Brazil, to protect ground water. Later, in December of the same year, Resolution number 91/2008 was passed by the National Council of Water Resources (CNRH), addressing general procedures for dealing with surface and ground water this is an invocative norm in the integrated management of water resources. It is also worth mentioning, that until now, ground water was not focused upon or even classified.

Thus, a paradox is formed, where the lack of an ample and systematic assessment of the potentiality of the aquifers is, at the same time, the cause and the effect of the lack of policy within the sector (Hirata et al. 2006). Protection programs, when they exist, are very outdated with regards to their real importance. Therefore, the definition and the implementation of consistent and pragmatic ground water protection policies are of the utmost importance in all Brazilian states. This policy needs to prioritize the definition of critical areas where:

1. The exploitation of ground water is intense.
2. The ground water resource cannot be substituted for any other source of water.
3. There is the evident presence of potential contamination sources that place aquifers at risk. In these critical areas, detailed studies aimed at solving the problem, should be a priority. On the first two cases, knowledge of hydraulics and of the potentiality of the resource and of the demands to which ground water are subject to, will allow one to define the best form of exploitation of the resource, by means of authorizations granted by managing agencies.

In the third case, focus is on the protection of the quality of ground water. In this case, the specification of critical areas should be done by means of maps that determine aquifer contamination vulnerability, in order to protect the aquifer itself, and by means of maps that determine protection perimeter of wells or sources, in order to protect public supply watershed or strategic watersheds. These specifications, together with the database on sources liable to contamination, will allow for the identification of the areas that present the highest risks and that demand the most environmental attention; they would also allow for the implementation of regional monitoring in these areas or for determining priorities for detailed studies.

In addition, also considered of extreme importance, are the economic assessments of the ground water resource and the economic, social and ecological costs involved in its exploitation, including those associated to overexploitation and to the contamination of aquifers.

Environmental education focused on water resources, and in particular on ground water is also a relevant tool for management. It is only by means of education itself that current and future generations will understand the role of ground water resources, and thus place the appropriate value on the water they don't actually see, but which carries equal importance.

In conclusion, despite ground water resources playing an essential role in human development in the country, its management is not in accordance to its strategic nature. The challenge faced by public management, by society and by those who use water, is to create and articulate actions that reflect a new form of relationship between man, land and water.

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Chapter 10
Availability, Pollution and Eutrophication of Waters

Corina Sidagis Galli and Donato Seiji Abe

Abstract Population growth coupled with the diversification of multiple uses, permanent intake of water for various purposes and the loss of the mechanisms of water retention has decreased their availability and produced numerous shortages. In urban areas this situation is worsened by the growth of irregular occupation and lack of sanitation system, which enhance the degradation of water quality and affecting the water systems as sources of water supply. These and other aspects related to availability and degradation of water resources by human activities are discussed in the present chapter.

Keywords Eutrophication • Pollution • Water availability and demand

Demand and Availability of Water in Brazil

Brazil stands out for its massive discharge of freshwater from rivers in its territory, whose average annual flow is of 179,000 $m^3 s^{-1}$, which corresponds to approximately 12 % of the world's water availability. However, due to the continental dimensions of the country, there are considerable regional disparities in terms of surface water availability. The Amazonian region holds, as an example, about 70 % of the surface water availability in an area equivalent to 44 % of the entire national territory, occupied by 4.5 % of the Brazilian population. The coastal region of the Eastern Northeast, occupied by 13 % of the population, only has 0.5 % of the available water, whereas in the coastal region of the Southeast occupied by 15 % of the population, there is only 2 % of water. Other regions, despite having elevated water availability, also have deficiencies. The Paraná hydrographic division, classified as comfortable with regards to demand versus water availability (MMA 2006), shows some critical areas,

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mainly in the state of São Paulo. A typical example is the Upper Tietê River basin, whose average annual rainfall is high, corresponding to 1410 mm (CETESB 2009), however, whose water demand is extremely high due to its elevated demographic density, seeing that since the Metropolitan Region of São Paulo, that has about 18 million inhabitants, is almost totally immersed in this basin. In addition, due to the soil having low porosity of the soil, typical of crystalline massifs, with low capacity to retain rain water, enhanced by the imperviousness resulting from intense urbanization, the volumes of water which are extracted from the watercourse and from ground water are hardly ever replenished, and as a consequence, the cities around the basin suffer floods during strong rainfall seasons. Aside from the soil low capacity of retention, there is also the problem of degradation of the waters resulting from the deficiency in collection and treatment of sewage produced in the basin, given the large irregular occupations that have precarious sanitation systems, even in areas of watershed protection. This combination of factors results in water availability per inhabitant per year in the Upper Tietê River basin being extremely reduced, of about only 200 m^3 $inhab^{-1}$ $year^{-1}$, in other words, very distant from the actual demand for consumption of the population residing on the basin, whilst the critical index as per the World Health Organization is of 1.500 m^3 $inhab^{-1}$ $year^{-1}$ (Jacobi et al. 2009). A similar situation can be seen in the Piracicaba-Jundiaí hydrographic basin (Fig. 10.1), also densely occupied, and therefore suffering the same consequences. This hydrographic basin unit, in addition, had the aggravating circumstance of having part of the waters of the basin being deviated to supply the water deficit of the Metropolitan Region of São Paulo, from the Cantareira supply system, that serves half of the population that lives there (Table 10.1).

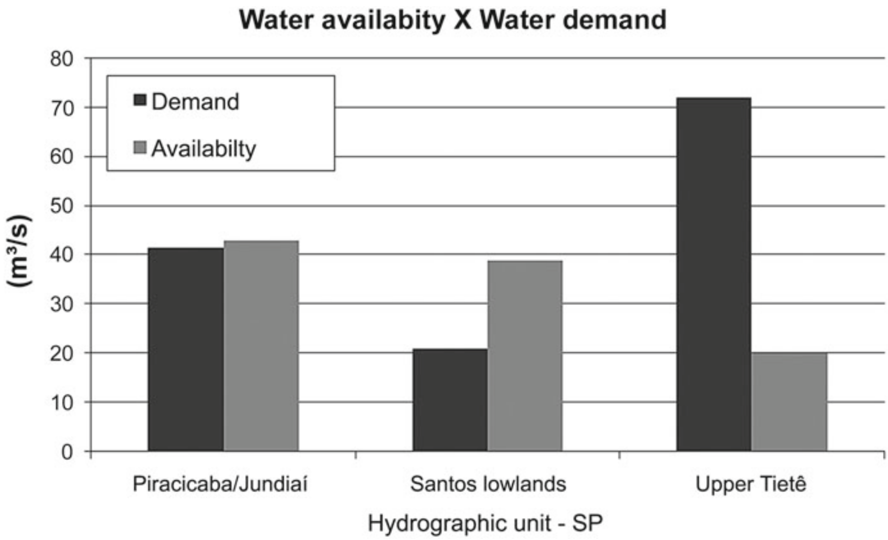

Fig. 10.1 Water availability and demand in the basin management units of Piracicaba-Jundiaí, Alto Tietê, Baixada Santista, State of São Paulo. *Source*: Mancini (2008)

Table 10.1 Water availability and demand in the hydrographic basin divisions of the Brazilian territory

National hydrographical division	Availability ($m^3 s^{-1}$)	Demand ($m^3 s^{-1}$)	Ratio demand/ availability (%)	Classification
Amazônia	73,748	47	0.06	Excellent
East Atlantic	305	68	22.30	Critical
Occidental NE Atlantic	328	15	4.57	Excellent
Oriental NE Atlantic	91	170	186.81	Very critical
Southeast Atlantic	1108	168	15.16	Worrying
South Atlantic	671	240	35.77	Critical
Paraguay	785	19	2.42	Excellent
Paraná	5792	479	8.27	Confortable
Paraíba	379	19	5.01	Confortable
São Francisco	1886	166	8.80	Confortable
Tocantins-Araguaia	5362	55	1.03	Excellent
Uruguay	565	146	25.84	Critical

Paraíba do Sul River Basin

The Paraíba do Sul River basin stands out for its location between the largest industrial and population hubs of the country and, as a consequence, presents multiple uses of water, generating conflicts. In the São Paulo portion alone, the Paraíba do Sul basin is home to about two million inhabitants, which corresponds to almost 5 % of the population of the State. Another important aspect of the Paraíba do Sul basin is the deviation of its waters to the hydrographic basin of the Guandu River, where the Guandu Water Treatment Station is located. This station treats about 45 $m^3 s^{-1}$ of water for 8.5 million inhabitants of the Metropolitan Region of Rio de Janeiro (MMA 2006). The Santa Cecília Pumping Station, which became operational in 1952, has the capacity of deviating up to 160 $m^3 s^{-1}$ of water from the Paraíba do Sul River, which is equivalent to about 54 % of the river's natural flow whose influx is guaranteed by several reservoirs located upstream, such as the Paraibuna, Santa Branca, Jaguari and Funil. According to MMA (2006), the division between the pumped flow to the Guandu basin and to the downstream of the Paraiba do Sul River, generates scarcity and conflicts over the use of the water resources, seeing that, on one side there is the need to supply the Metropolitan Region of Rio de Janeiro aside from industries and other users; and on the other side, there are several cities and users, especially in the path located immediately downstream of the station, in critical inflow situation, with low flows and consequent deterioration of the water quality. Users upstream are in turn conditioned upon being supplied by the flow sent to Santa Cecilia. Following the creation of the Brazilian Water Agency (ANA), operational conditions have been defined by this agency and shared with the National Operator of the Electric System (NOS), in a joint effort with the basin committees and with all the other areas involved, such as water resource users, the government in all its spheres and the agencies of the civil society.

Increase in water consumption embedded in the production of food and industrialized products, the virtual water.

Based on the predictions presented in the Worldwide Water Assessment Program (UNESCO 2009), the greatest controlling factors of the worldwide water resources, generated by human activities, will be the demographic alterations and the increase of the standards of consumption, resulting from the increase of income "per capita" especially in the countries with increasing economic growths and with current elevated populations. The increase in income will allow for a greater general consumption on behalf of the population and additional water will be needed for the production of food and other goods and services. In this perspective, according to Tucci (2009), water will become an important merchandise commodity in the world's market, embedded in the production of food and industrialized products (virtual water), leading countries like Brazil, with availability of land, water and productive capacity, to have their markets valued. However, the author pointed out the fact that management has not yet rendered the necessary importance to this product within the productive chain, being this, the main challenge to be faced, aiming at a greater efficiency, sustainability and financial return.

Pollution of Waters

The environmental health of a water body of water is affected by human activities developed within its hydrographic basin watershed, including: (1) launching discharge of domestic sewage; (2) receiving of rainwater that runs off agricultural areas and over soils subject to erosion; (3) receiving of rain water that comes from regions with atmospheric pollution, such as, for example acid rains; (4) percolation of leachate from landfills close to bodies of water bodies; (5) toxic compounds from pesticides used in agriculture and in reforestation; and (6) waters contaminated by xenobiotics, resistant organic compounds and traces of pharmaceutical products (Bernhardt 1990). All these factors induce the degradation of water quality, the loss of biological diversity and the waste of water resources (Straškraba and Tundisi 2008). According to these same authors, there is a strong relationship between the degree of pollution and the density of the population and the three factors that govern this relationship are: (1) urbanization, (2) industrialization and (3) development of agriculture on a large scale. Population increase and the consequent urbanization reduce, together with the increase of agricultural areas, the capacity of hydrographic basins retaining water and their natural capacity of retaining pollutants.

In Brazil, the use of surface waters as a source of public supply continues to be the mostly used watershed alternative. Based on information from ANA (2003), 56 % of the total amount of cities in the country, use surface water as at least one of their watershed alternatives. However, it has been observed that this alternative is the most exposed to the sources of pollution and contamination. One can observe, for example, one or more ways of pollution and contamination in 26.7 % of the total amount of cities with surface catchments, of which 14.24 % of them present contamination due to domestic sewage discharge and 16.22 % of them due to agro toxic residues. One of the consequences of this fact is the elevated level of hypertrophy seen in some surface bodies of water, especially those located in metropolitan regions, which continuously receive an excessive amount of organic matter. The remaining domestic organic load estimated for the country is of 6377 ton DBO day^{-1}, of which only two of the main population centers of the country, the metropolitan regions of São Paulo and Rio de Janeiro, are responsible for about 20 % of this total. With regards to the organic loads of animal origin, it is important to mention those from pig farming, especially in the hydrographic region of Uruguay, where the biggest Brazilian herd is located. In this region, the organic load generated by swine and discharged into the bodies of water is greater than that of human origin.

Cost of Treatment

The increase of the degradation of water directly affects the cost of treatment. The immediate consequence is the increase of the quality of chemical products necessary to treat this water, given the need to maintain water quality for supply. In the Guarapiranga System for example, where the production of treated water is of 14 $m^3 s^{-1}$ to supply 3.8 million people from the Metropolitan Region of São Paulo, there was an increase in the quantity of chemical products of 20 % from 2001 to 2004 (Fig. 10.2), thus, elevating the cost, which is reflected on the price to the final consumer. A totally different situation can be seen in the Cantareira System, where the quantity of chemical products for treatment did not have a considerable increase, seeing that human occupation on the basin did not grow as significantly during the same period.

However, aside from the increase in the quantity of chemical products being used for treatment, degradation of the water quality require more sophisticated treatment processes, such as the use of activated carbon to remove the taste and odor from the water and the use of potassium permanganate for degradation of organic matter. These processes make the costs for treatment of water even higher.

Eutrophication

Eutrophication of inland water bodies of waters consists of the enrichment of water by nutrients, especially phosphorus and nitrogen, which come as solutes and are transformed into organic and inorganic particles. The accelerated growth and the greater abundance of aquatic plants frequently cause deterioration of the water quality and growth of a large volume of algae, including potentially toxic cyanobacteria, becoming a risk to the health of the ecosystems, aside from resulting in an increase of cost for water treatment for supply.

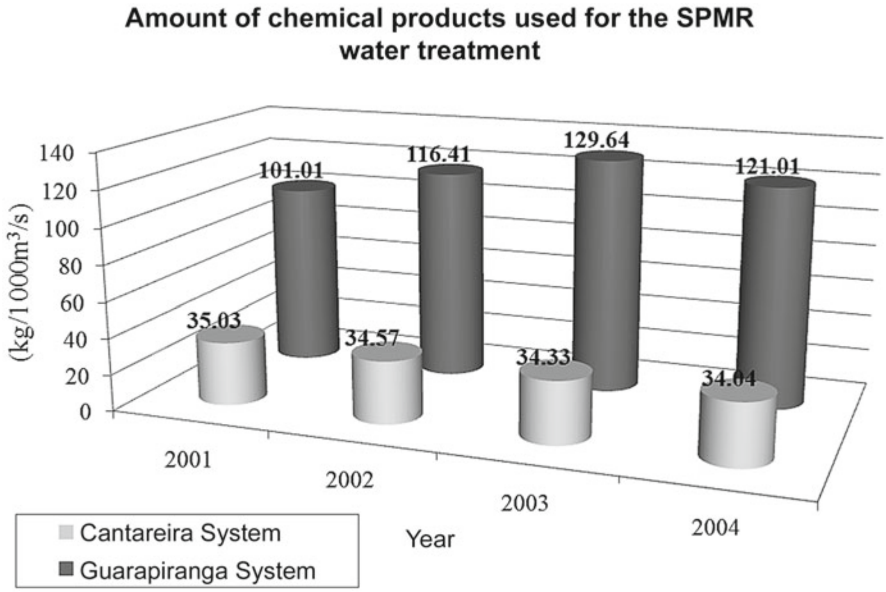

Fig. 10.2 Quantity of chemical products used for water treatment in the Metropolitan Region of São Paulo between 2001 and 2004. *Source*: SABESP

The increased load of nutrients in the water usually occurs due to changes in the watersheds, such as: removal of forests, agricultural and industrial development, but mostly, due to the increase of urbanization (UNEP-IETC 2001). The relationship between urbanization and eutrophication became evident in the "Waters of Brazil Project", in which 1162 locations were identified in water bodies in Brazilian territory by using an amphibious airplane. The highest concentrations of total phosphorous were observed in the Northeast Eastern, Southern Coastal, Southeastern Coastal, Paraná and Eastern Coastal Basins, which show greater demographic densities and where the population represents 75 % of the country's total (Abe et al. 2006) (Fig. 10.3).

One of the most evident consequences of the increase of the trophic state of a water body is the booming of algae, which affects the treatment process and alter the taste and odor of treated water.

Some species, especially of cyanobacteria, are potentially toxic and can make the use of water bodies of impracticable for public supply and other essential uses, due to the risk of causing serious impacts to human health. This phenomenon is not restricted to watersheds of large cities. Researchers have already identified the presence of several species of cyanobacteria in dams of the Northeastern semi-arid region of Brazil due to elevated temperatures and due to deficiencies of the sanitation system in the region (Bouvy et al. 2000; Costa et al. 2006; Panosso et al. 2007). In fact, studies have revealed favored conditions for cyanobacteria and toxic blooming in temperate lakes in Europe with the increase of temperatures during

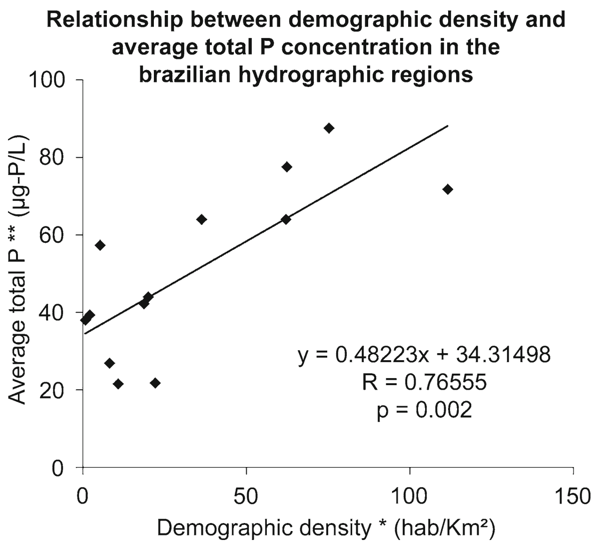

Fig. 10.3 Relationship between demographic density and total phosphorous mean concentration in Brazilian basins. (*) data from the 2000 IBGE Census. (**) data from 1162 stations in water bodies of the Brazilian Territory by the Waters of Brazil Project. Adapted from Abe et al. (2006)

the summer, under the influence of global warming (Bicudo and Bicudo 2008), even after having undergone restoration processes with the reduction of the load of phosphorous. These studies indicated the worsening of eutrophication and a lower efficiency of the recovery processes of the continental lentic systems as a result of global warming.

A recent review performed by Smith and Schindler (2009) specified cultural eutrophication as the greatest problem of current times in surface bodies of water, considering it to be one of the most visible examples of alterations caused by man to the biosphere. Aside from the effects already amply described caused by the excessive intake of phosphorous and nitrogen in lakes, reservoirs and rivers (Table 10.2), the authors describe other direct and indirect effects caused by cultural eutrophication. As an example, in several bodies of water, the increase in the intake of N and P can accelerate the biodegradation process of petrochemical products, aromatic hydrocarbons and pesticides, seeing that the increase of the trophic state encourages the increase of bacterial biomass and, as a consequence, an increase in the diversity of organic substrates, which bacteria are able to metabolize. At the same time, the increased intake of nutrients can influence abundance, composition, virulence and the survival of pathogens which reside in aquatic ecosystems. The increase of the availability of N and P in the water for example, promotes the increased rate of water virus replication. Likewise, the increase of eutrophication can promote the increase in the abundance of *Vibrio cholerae* vectors and of some copepod species thus influencing the probability of the occurrence of cholera epidemic in human populations susceptible to the disease.

Table 10.2 Potential effects of cultural eutrophication caused by the excessive intake of nitrogen and phosphorous in lakes, reservoirs and coastal regions

Eutrophication effects
• Phytoplankton and aquatic macrophytes biomass increase.
• Consumers' biomass increase.
• Biomass increase of potentially toxic or not edible algal species.
• Benthic and epiphytic algal species biomass increase.
• Modification in the macrophytes species composition.
• Fish death frequency increase.
• Decrease of cultivating fish and mollusks' biomass.
• Decrease of species diversity.
• Decrease of water transparency
• Flavor and odor and problems in the supply water treatment.
• Depletion of dissolved oxygen.
• Decrease of the water body aesthetic value.

Adapted by Smith and Schindler (2009)

Effects of Eutrophication

1. Increased biomass of phytoplankton and macrophyte vegetation.
2. Increased biomass of consumer species.
3. Shifts to bloom-forming algal species that might be toxic or inedible.
4. Increased biomass of benthic and epiphytic algae.
5. Changes in species composition of macrophyte vegetation.
6. Increased incidence of fish kills.
7. Reductions in harvestable fish and shellfish biomass.
8. Reductions in species diversity.
9. Decreases in water transparency.
10. Taste, odor and drinking water treatment problems.
11. Oxygen depletion.
12. Decreases in perceived aesthetic value of the water body.

Eutrophication and Greenhouse Gas Emission

The increased load of organic matter and nutrients in the bodies of water also causes an increase in the emission of greenhouse gases into the atmosphere. With the increase of the production of biomass due to increase of intake of nutrients, there is also an increase in the quantity of biomass formed by dead organisms or by fecal particles that sink and accumulate in the sediments of reservoirs. With this accumulation of organic matter in sediments, there is an increase in nutrient cycling, especially of carbon, nitrogen and phosphorous, which is mediated by microorganisms that ultimately results in the production, accumulation and emission of gasses such as CO_2, CH_4 e N_2O. Studies performed by Abe et al. (2008) show that more eutrophic reservoirs have higher diffusive fluxes of greenhouse gasses when compared to less eutrophic reservoirs. In the Furnas Reservoir, in the state of Minas Gerais for example, one can find superior concentrations of organic matter, total nitrogen Kjeldahl and total phosphorous in the Sapucaí branch when compared to the values observed in the Grande branch. The Sapucaí branch of the Furnas Reservoir receives a greater impact than the Grande branch due to the large human occupation on its watershed. As a consequence, superior diffusive fluxes of CO_2 and CH_4 were observed in the Sapucaí branch of the Furnas Reservoir in comparison to the values of the Grande branch.

In the reservoirs of the Middle Tietê River, in the state of São Paulo, a study was performed to verify if the trophic state of the reservoirs is related to the emission of greenhouse gasses in the interface water-air (Abe et al. 2009). Bearing in mind that the reservoirs of the Middle Tietê River, displayed in cascades provide a decreasing gradient of eutrophication, in other words, the Barra Bonita Reservoir is classified as eutrophic-hypereutrophic, the Ibitinga Reservoir as eutrophic and the Promissão Reservoir as oligotrophic-mesotrophic, the authors noticed that the maximum fluxes of CH_4, CO_2 and N_2O were observed in the Barra Bonita Reservoir, i.e. the most eutrophic of the two, and the lowest fluxes in the Promissão Reservoir (Fig. 10.4). The authors also observed that the diffuse fluxes of CH_4 and N_2O presented a high correlation with the concentrations of total nitrogen and total phosphorous in the different reservoirs, which clearly demonstrates that the levels of emission of these gases are directly related to the level of eutrophication of the system.

It is essential to realize that the high emissions of greenhouse gases in the reservoirs of the Middle Tietê River originate in the mismanagement of the water resources in the basin upstream and not by the existence of the reservoir itself. If there were satisfactory treatment of domestic and industrial sewage in the Metropolitan Region of São Paulo, for example, such emission in the Barra Bonita Reservoir would be similar or even lower to those observed in the Promissão Reservoir (Fig. 10.4). These results showed that the management of water resources focused on reducing eutrophication has become imperative not only to avoid the evident impacts, such as the reduction of the aquatic biodiversity, fish mortality and blooming of potentially toxic cyanobacteria, but also in order to avoid the emission of greenhouse gasses to the atmosphere and consequently to decrease global warming.

Final Considerations

As addressed in this chapter, Brazil shows great regional disparities in terms of surface water availability. The situation becomes critical in regions of elevated demographic density due to the high demand for water. However, it becomes even more severe due to the deterioration process of the water quality which results from

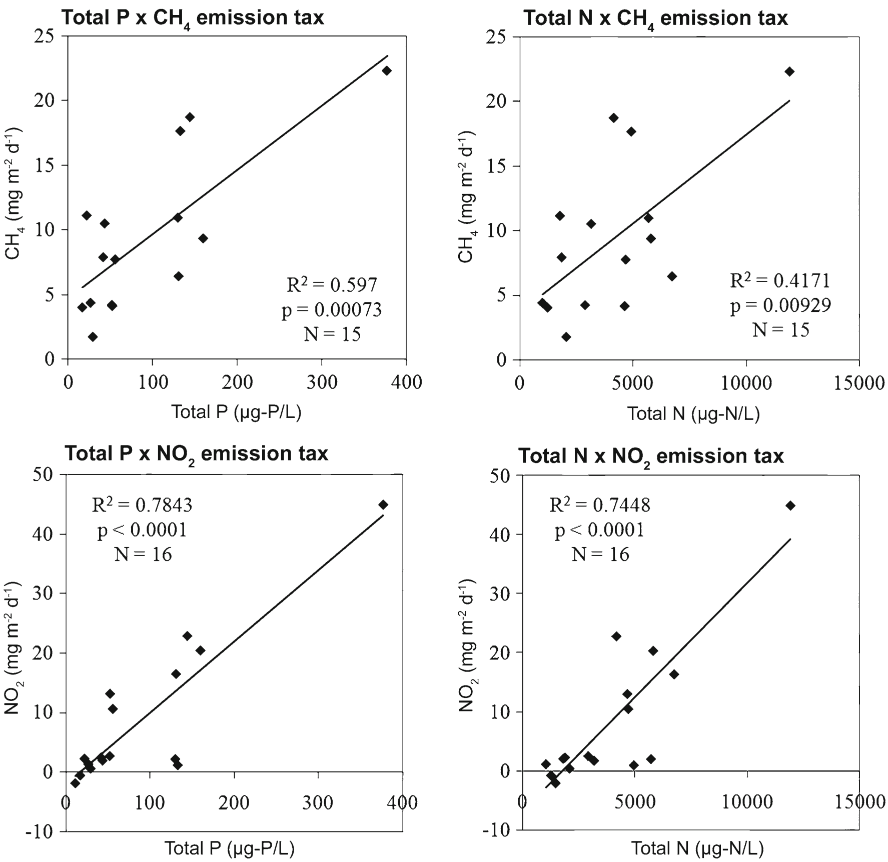

Fig. 10.4 Correlation between total nitrogen, total phosphorus and the rates of emission of CH_4 and N_2O through the water-air interface in the Medium Tietê River reservoirs. *Source*: Abe et al. (2008)

anthropogenic activities that exist in the watershed, resulting in an increase in the costs of treatment or even making the use of the water for supply impracticable.

The most evident degradation process of water resources in the Brazilian territory is that which results from the domestic sewage loading, since the level of treatment is still very low, thus worsening the process of eutrophication. Aside from resulting in known impacts, such as the loss of aquatic biodiversity, the blooming of potentially toxic cyanobacteria, the excessive growth of aquatic macrophytes, anoxia and fish mortality, the increase of eutrophication, mainly in reservoirs, results in the increase of greenhouse gas emission, which consequence is the aggravation of the global warming process. With this in mind, urgent action needs to be taken to minimize the effects of eutrophication in the aquatic systems, above all with regards to the treatment of domestic sewage, supported by strategic programs linking scientific knowledge with public policies. Such actions are already being taken and have shown positive results in the European Union, based on the specification of goals to improve the ecological quality of waters.

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Chapter 11
Science, Technology, Innovation and Water Resources: Opportunities for the Future

José Galizia Tundisi and Takako Matsumura Tundisi

Abstract In this chapter, we emphasize the importance of promoting a more effective integration between Science, Technology and Innovation with an integrated management of water resources and water governance. Investments in research in the areas of contamination and eutrophication, persistent organic pollutants, technologies for monitoring and studies of bioindicators should promote a more efficient management of the surface and ground water at a hydrographic basin level. Technologies for desalination and reuse of water will promote advances in reducing demand and in regional water economy. For the organization of scenarios, the implementation of ecological and mathematical models will be essential when selecting new opportunities and alternatives for management. Furthermore, the economic value of the services rendered by ecosystems can add new perspectives for using economic tools within the management of waters. A more effective interaction among ecologists, limnologists and engineers is required in order to achieve a systemic perspective; and the implementation of strategic studies should enable new possibilities in integrated and predictive management, at a watershed level.

Keywords Innovation • Integrated management • Science • Technology • Water resources • Watershed

Introduction

The relationship availability/demand regulates the water cycle of the continents and regions, especially when considering human population needs and the impacts of their activities on water resources. Quality of life and human health, the development of the economy—weather regional or in all of Brazil, depend not only on the availability of

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water, but also on the quality of this water. Thus, quantity and quality go together, and the future of Brazil's social and economic development depends upon both.

Despite the undisputable progresses in the management of waters in Brazil, as shown by Braga et al. (2006a, b), and the advances in the technological field and in the areas of scientific knowledge which occurred in the last 10 years (Tundisi and Matsumura-Tundisi 2008), there is still the need for considerable investments in Science, Technology and Innovation, to meet the needs of the water resource management system, focused on a scientific and technological basis capable of consolidating the verified progresses and promoting new perspectives for the future. In this chapter, we aim to address the role of Science, of Technology and of Innovation as one of the necessary components for the implementation of a new and creative approach to management processes, to monitoring, to use of technologies and to resolving problems regarding the provision of adequate amounts of surface and ground water resources, also focused on better water quality and therefore promoting environmental sustainability.

The Economic Value of Water

The economic value of water is, as Lanna and Braga (2006) pointed out, related to human society's needs for surface and ground water resources, especially with regards to its multiple uses and scarcity. This scarcity, which is dependent on regional water cycle and on availability/demand, may not only be related to the quantitative aspects, but also to the excessive pollution of the water resources which will render the water unavailable due to the high cost of treatment. Therefore, pollution of water resources may also be the cause of scarcity.

One of the problems most discussed by economists who work with "nature values" is the concept of the value of water resources. The distinction between the economic value, price and market values is essential when dealing with water.

Water is essential to human life and to the entire life and biodiversity of the planet. This value goes beyond the "market value", in other words, in the value determined in monetary terms.

However, the value of water as a "natural resource" available for multiple uses requires other conceptions and approaches. In 1956, the state of California in the United States, hired a consultancy company to evaluate the recreational benefits of water associated to a planning program on Waters in the state of California (Hanemann 2006). A study was performed on visitors of the natural lakes of the state and how much they would spend to visit, to observe, on recreation and on leisure. Following these first assessments, other evaluation attempted to demonstrate the value of the natural ecosystems and their multiple uses, especially of waters of rivers, lakes, artificial dams and flooded areas. The value of water lies, as stated by Baumann and Boland (1998) and Barlow and Charbe (2002), somewhere between the value of a commodity such as food, housing, clothes, and a "natural value", of which all species of the planet depend upon for survival. Water has a special meaning which goes much beyond being a commodity like food or land, for agriculture for example.

The economic assessment of water is therefore essential for the future: agriculture and production of food, energy, and transportation are a few of the multiple uses of the water in Brazil which require an economic evaluation of the role surface and ground water resources play in the regional and Brazilian economies. Conflicts over the use of water for irrigation for example, as opposed to public supply, already occur in some regions of Brazil (Lanna and Braga 2006) which exemplifies the need for a progressive evaluation of the water dependent economies. Tundisi (2009) performed an economic assessment of the Guarapiranga and Billings dams, in the metropolitan region of São Paulo, and emphasized values such as the production of water for supply, sources of recreation and tourism and investments in permanent housing for tourism. Vergara (1996) performed an assessment of the economic value of the UHE Carlos Botelho dam (Lobo/Broa) in Itirapina, Brotas, and reached a value of R$ 320 million reais (value corrected for 2009) in investments for recreation and tourism.

The diversified and multiple uses of water in Brazil require a permanent assessment and monitoring. As an example, the typical consumption of water of irrigation systems (Table 11.1) can be compared to different types of technologies being used and the quantity of water in demand by the different technologies.

The charging for the uses of water, therefore, has a well-directed and practical economic foundation. Table 11.2 shows for example, the relationship of water consumed by rice and by sugar cane as a basis for the billing for its use.

Table 11.1 Water consumption in irrigation systems

Irrigation method	Continuous vazão ($L\ s^{-1}\ ha^{-1}$ 24 h)	Daily consumption ($m^3\ ha^{-1}$)	Equivalent population (inhabitants)
Dripping	0.35–0.80	30–44	300–400
Micro aspersion	0.50–0.70	44–61	440–610
Aspersion (all types)	1.00	86.4	864
Infiltration	1.20	103.6	1036
Flooding	2.00–2.50	>121	>1210

Source: Lanna and Braga (2006)

Table 11.2 Water consumption for rice and sugar cane

Rice	Sugar cane
Cycle 120 days	Cycle 270 days
Consumption 2.0 $L^{-1}\ s^{-1}\ ha^{-1}$ =20,136 $m^3\ year^{-1}\ ha^{-1}$	Consumption 0.71 $L^{-1}\ s^{-1}\ ha^{-1}$ =16,600 $m^3\ year^{-1}\ ha^{-1}$
Efficiency 40 %	Efficiency 39 %
BOD none	BOD none

ha = hectare; L = liter
Source: Lanna and Braga (2006)

Besides, valuing of natural systems of water resources needs to progress in order to supply the necessary conditions for a more efficient and integrated management beyond the exclusive economic value (Whately and Hercowitz 2008). It is essential to perform a management of water based on economic tools, which will need to increase in accordance to the increase of multiple uses and to the increase of scarcity. Naturally, there is a tendency to emphasize the economic value of water based on the increase of the multiple uses.

And the other management tool related to the value of water resources is related to the "natural value", which needs to include water mobility and their flows, variability of regional waters and hydrological cycles and the spatial variation of supplying availability/demand for multiple uses.

The economic assessment of the impacts of pollution of surface and ground water resources in the costs of water treatment for supply is another much needed area to be focused upon. Performed assessments show that the cost of treatment of water from watershed to make it potable vary from R$ 2.00 (two reais) to R$ 400.00 (four hundred reais) per thousand treated cubic meter. This difference is the economic cost of pollution of watersheds. One should note that this cost only refers to the necessary chemical products for the treatment, and not to costs related to (Tundisi 2003).

Two other problems also need attention with regards to water and economy. The first one is the economic loss due to pollution, as was previously mentioned. In addition to the costs of treatment, the impact on human health should also be taken into consideration. The second problem, which requires scientific and technological investigation, is the strategic value of the water resources for Brazil. The multiple uses and Brazil's dependency on water for sustainability require this evaluation in order to make long term strategic decisions.

Water Resources and Nature: The Ecological Cycles and the Water Resources: Theories and Their Implementation in Management

The ecosystems provide services to the human species that are extremely relevant to the water supply riparian forests and head waters; they regulate the water flux, reduce the transport of suspended matter to the rivers and influence the recharge of aquifers. Flooded areas work as filters purifying the water and controlling flows and floods. Rivers and lakes are sources of animal protein. All these "environmental services" have a benefit which is directly related to local communities (MEA 2003).

The most comprehensive and promising approach to water and their relationships with the natural ecosystems is that which considers the environmental flows related to the water regime and their interactions with rivers, flooded areas and natural lakes. These environmental flows, which are on one hand an essential part of the hydrological cycle and regulate the physical, chemical and biological characteristic of surface and ground water resources, are also on the other hand the basis for the Integrated Management of the Water Resources, considering the hydrographic basins and their flows as their core element (Fig. 11.1).

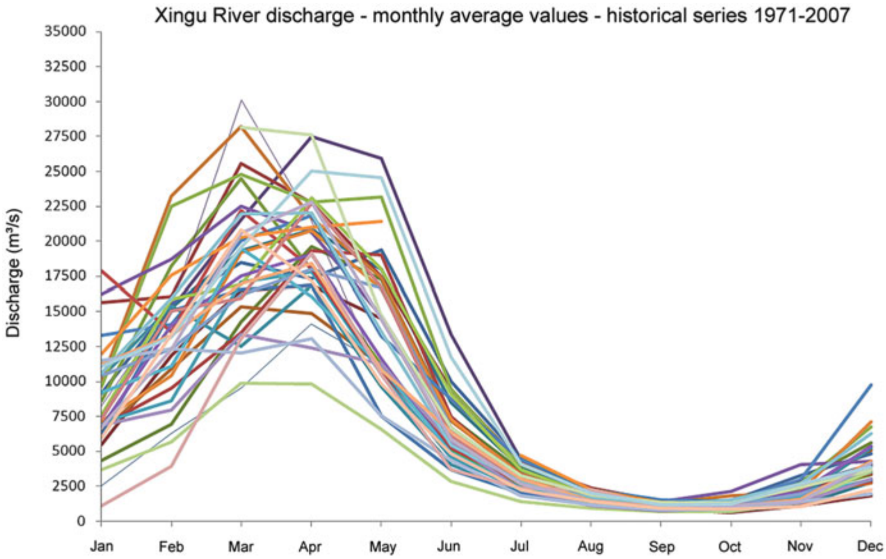

Fig. 11.1 Historical series of flows of the Xingu River. This historical series of the hydrological cycle shows how flows, which vary annually, can be essential factors in the control of the biogeochemical, chemical and biological cycles. *Source*: EIA/RIMA/AHE Belo Monte (2009)

It is essential to scientifically understand the relationship between the state of the ecosystems and the infrastructure of water resources. The ecosystems are not simply "economic users" of the water resources; they are also part of the supply chain and availability of water (Bergkamp 2006).

One should highlight that the development of life on planet Earth explored the aquatic environment and the availability of water in many different ways. Water is the source and sink of gases, ions, minerals and dissolved and particulate organic matter. Water, as a universal solvent, dissolves an enormous set of substances, both of a natural origin as well as of an artificial origin, produced by the innumerous and diversified human activities. All organisms have vesicles that contain water and solutions of organic and inorganic substances. Its composition is controlled by permeable membranes and the transport made available through these membranes.

Water plays an important role in the dissolution of soils, and the ionic composition of rivers and lakes is related to regional hydrogeochemistry. On the other hand, aquatic animals from protozoa to vertebrates have an essential relationship with water, with its chemical composition and its physical characteristic such as turbulence.

Rainfall is one of the essential characteristics of planet Earth. Each year, rainfall transfers to continents 108,000 km^3 of waters with low mineral composition which are drained at different levels. The continuity of the processes lies in water interfering in the morphology of the continents, rivers and lakes, transporting substances and maintaining flow is essential. Human interference has caused alteration to these water cycles and to how they function with the terrestrial and aquatic ecosystems.

Garcia-Novo and Garcia-Bouzas (2006) show the following consequences of human interventions in the crucial water cycles and in the functioning of ecosystems:

1. Eutrophication of continental waters.
2. Eutrophication of coastal waters.
3. New organic molecules dissolved in water and added to domestic effluents: hormones, medications, antibiotics and blood pressure controllers.
4. Growing demand for water in urban regions and agricultural areas.
5. Growing demands from industries.
6. Introduction of exotic species in aquatic systems of all continents.
7. Fragmentation of rivers, due to the increase in constructions of chains of reservoirs.
8. Technical alteration and overexploitation of aquatic organisms affect the hydro social cycle and the cultural traditions related to rivers and lakes.
9. Navigation and transport: alter habitats, pollute rivers, lakes and dams, discharge ballast waters introducing exotic species.

These processes occur in Brazil at several levels, at greater or lower intensities in the different regions, latitudes and natural and artificial ecosystems of the country, thus requiring immediate innovative researches and a speedy implementation. All these processes require investments in research and innovation, with a more in depth scientific knowledge of the hydrological, biogeochemical and hydro social cycles, with studies on bioindicators and their regional uses. They require diversified actions with methodologies and high quality equipment to identify and monitor persistent organic pollutants dissolved in the waters of the watersheds. Also necessary are studies on toxicity of cyanobacteria and on effectively controlling eutrophication, aside from new technologies to recover hydrographic basins, rivers and dams (PNUMA/IIE 2008, AIIEGA, PMSP/SVMA 2009) at a larger scale and with a greater intensity (Tundisi and Straškraba 1999).

A lot of progress has been made in this area in the last 20 years in Brazil (Bicudo et al. 2006; Agostinho et al. 2007). However there is the need to not only further pursue these studies, but also to continuously promote the transfer of principle, concepts and theories for their implementation. This means that the sharing of ecological principles to be used as technological solutions need to be accelerated and the language and concepts of engineers, ecologists and limnologists need to be made accessible (Straškraba et al. 1993; Tundisi and Straškraba 1995). Monitoring of ground water and studies regarding the sources of contamination of deep wells are also essential within this context.

The Technological Basis for the Management of Water Resources

The three great problems which affect the management of water resources in Brazil and that require a strong academic support are:

1. A better understanding of the interactions between the terrestrial systems (uses and land occupation) and the aquatic systems.
2. A constant and growing unbalance between availability and demand over water.
3. The growing contamination and eutrophication, rending considerable volumes of water unavailable, especially in the Southeast and South regions.

Following, a discussion on the inputs of research needed to solve these crucial problems:

Facing the Challenges of Eutrophication and Contamination

Eutrophication and contamination of water resources have accelerated the unavailability of water, limiting the population's access to supply sources, increasing costs for treatment, increasing the population's vulnerability and collective safety with regards to human health. Somlyody and Varis (2006) describe the following trends in relation to eutrophication and contamination of surface and ground water:

1. The scale of the problem is increasing, from local to global.
2. As a consequence of the pollution of the soil, the sediment and of the ground water, the impacts as well as the recovery results exhibit significant delays.
3. On any lake, dam or watershed there is an overlap of problems: excessive use of land on the hydrographic basin in rural and urban areas, discharge of domestic sewage and contamination from inorganic substances and elements (heavy metals and organic such as pesticides, herbicides and other toxic elements) dissolved in the water.
4. Global alterations can accelerate processes, negatively alter certain trends and render the interaction and synergies even more complex.

It deals therefore, with complex systems of contamination and eutrophication, whose synergies require considerable scientific and technological investments: new systems for treatment of water and decontamination, epidemiological assessment of the impacts of eutrophication and pollution on human health, advanced new systems for real time monitoring and researches about decontamination techniques and control of eutrophication; contaminated sediments for example, have high costs for removal of metals and other elements (Mitsch and Jorgensen 2004) and the impact of this contamination can be permanent or long term.

There is also the need for a set of researches about bioindicators, tolerance of organisms to different concentration of toxic substances and the need for developing adequate methodologies for the implementation of certified techniques or ones that measure the effects of toxicity.

Eutrophication and contamination are components of the same degradation process, and the results of the effects of the loads from point and nonpoint sources, have, aside from deterioration and the decrease of aquatic biodiversity, economic causes, for they demand investments towards the reduction of long term impacts and effects to human health (Tundisi 2006) (Fig. 11.2).

Fig. 11.2 Eutrophication of reservoirs such as the Barra Bonita Dam can interfere in the functioning of locks and turbines. Photograph: J. G. Tundisi

Emerging processes resulting from contamination by persistent organic pollutants (POPs) also require scientific investigation and investments into detection and monitoring systems, as well as into the creation of sophisticated processes for treatment. The assessment of the effects of endocrine disruptors on human health is, up to a point, practically unknown. One should also highlight that there is the need, due to the fact that we are dealing with a country of continental dimensions with water resource distributed unevenly in a latitude range that goes from 5°N to 35°S, to focus researches in very different conditions than those conducted in temperate regions. There is the need to seek and develop new quantitative assessments of impacts, of producing new sets of indicators and therefore, the research should also promote regional actions and implementations. Solar radiation, water temperature, hydrological cycles, aside from substantially differing from the standards of temperate regions where a large part of the research and of the technology was generated, also present regional peculiarities that need to be addressed in scientific research and innovation in this area.

Potentiality of Desalination: Innovative Technologies and Perspectives for Brazil

For any society, the minimum value of 1000 m^3 per capita^{-1} year^{-1} is considered the standard index below which the chronic shortage of water can be considered a project for development with negative effects on human health. The total consumption of water in the planet is currently of 40,000 km^3 $year^{-1}$ (Rogers et al. 2006). With the increases in demands for water, a greater scarcity may occur in certain regions, at levels considered critical to the quality of life and human health. Even though Brazil has water reserves estimated to vary between 12 and 14 % of the planet's water reserve, there are critical geographic areas, with scarcity, with an unevenness of availability (demand), water stress (conflicts over multiple uses) and lack of water (low levels of water—availability—in high areas of the semi-arid regions) (ANA 2009).

In order to increase availability of water for human supply and for other uses, desalination can be a viable alternative, especially if one takes into consideration that Brazil has 8000 km of coast, with a high level of coastal water availability for desalination.

Desalination, however, is a process which depends upon the use of energy. The total energy used to operate all of the existing desalination plants corresponds to 0.3 % of the primary energy in terms of fossil fuels consumed in the entire world (Uche et al. 2003). One of the alternatives to reduce the use of energy for desalination is the use of renewable sources such as, wind energy for example.

There are several technologies available for desalination. Costs which 10 year ago were quite high (US$ 1.00 m^3) are now lower (US$ 0.30 m^3), which can render desalination process viable. One of the commonly used techniques is the reverse osmosis, in which the water from the ocean (coastal water or brackish water from estuaries) is desalinized at an energy cost of 3–5 kWh m^3 (Uche et al. 2006). In 2002, it was estimated that there were 15,233 desalination units in all countries and continents.

In Latin America, in the Caribbean alone there is an investment in desalination with a production of 724,000 m^3 day^{-1} of fresh water. In other countries of Latin America, Chile (131,000 m^3 day^{-1}) and Mexico (285,000 m^3 day^{-1}—industrial uses and tourism regions) are the main producers.

The costs of these desalinations vary, according to technology, availability of energy and aces to coastal and estuary areas. In general, these costs range from € 900 to 550 m^3 day^{-1} for membrane desalination, up to € 1600 m^3 day^{-1} for multistage flash distillation.

In Brazil's case, the need for large supplies of water for urban regions will still be able to use freshwater from rivers and dams. However, the main needs lie in small desalination plants (10,000–100,000 m^3 day^{-1}), with capacity to supply villas and small housing projects in the interior, where surface and ground water is brackish or has a high level of salinity. This is where the need for technological investments to develop efficient desalination systems operated in these areas lie. The cost of energy is the main expenditure for desalination (more than 50 % of the cost). The use of small desalination plants can be useful in condominiums or buildings in coastal areas, where there is also the need to reduce the demand over continental freshwaters.

Desalinized water for public supply needs to be recomposed with mineral and CO_2 and $CaCO_3$. This water can also be used for small scale irrigation.

Thus, desalination can be a favorable technology for future use in Brazil. Researches and Technological Developments are crucial to reduce the costs of the processes, to render it usable especially in coastal areas with scarcity of freshwater from the continents and to lower the consumption of energy used in desalination.

This is one of the technological challenges which Research Institutes, Universities and Technological institutes can deal with.

The use of desalination plants on a large scale to supply large coastal cities can become viable based on the researches and technological development which are implemented in the future. It is a possibility which should be looked into by future strategic studies. Researches with chartering of saline water systems—flocculation, sedimentation and filtration—should contribute towards reducing the costs. Membrane systems require larger investments in research and technology. There is also the need for investments in reducing environmental impacts of desalination: accumulation of saline residues, how to reduce the addition of less aggressive chemical products to the environment and how to reduce thermal pollution, one of the sub products of the process in certain desalination technologies.

The Reuse of Water: Facing Scarcity

As pointed out by Asano (2006a, b) and Hespanhol (2008), one of the relevant solutions in facing water scarcity and reduce demand, is to reuse water after residential water is treated. Hespanhol (2008) emphasized that the water resource management policy should include reuse of water as an essential component, which would bring important benefits in the economic and social points of view, aside from environmental benefits.

Reuse should not be limited to semi-arid and arid regions, in fact it can also be used in regions of scarcity and water stress, as is the case for example of the Metropolitan Region of São Paulo (RMSP). The AGENDA 21, as per Hespanhol (2008) in his chapter in the pragmatic area B, emphasizes the need for growth and consolidation of the national systems of reuse and recycling of wastes, and in the specific case of water resources, emphasizes the need of making technologies available and appropriate management tools focused on recycling and water reuse.

Water reuse involves consideration and assessments of water supply, human health, infrastructure, treatment systems, and most importantly, the creation and preparation of quality standards that can render reuse viable. The decentralization of this reuse at a municipal level, making valuable sources of water available for several uses, is one of the most adequate mechanisms to locally optimize reuse of treated residential waters. There are several constraints for reuse to be implemented: safety for public health, proximity to sources of residential waters, competitive demands for the multiple uses of water and specific standards of water quality.

Waters from reuse can be utilized for the following:

1. Irrigation in agriculture.
2. Irrigation of parks, gardens and golf courses.
3. Industrial use for cooling, construction, water for thermal heating.
4. Recharge of aquifers: control the quantity of water of aquifers, maintain water in underground wells.

5. Recreational and environmental uses: lakes, areas of artificial flooding, fishing.
6. Non-potable urban uses: firefighting, use in air conditions.
7. Potable use: mixed with natural sources or discharged in supply reservoirs.

In Brazil there is still no legal framework to regulate the reuse of water. However, the already existing initiatives, mainly in industries (that managed to reduce water consumption ranging from 40 to 80 %), increasingly show a greater willingness to reuse treated residential waters, from several origins and using several different technologies.

Aside from the reuse of treated residential waters, one should consider that Rainwater can also be a viable alternative in several regions, thus eliminating demand and leaving natural water resources exclusively for domestic supply. Inserting the use of this "blue water" into the management process of water resources is another very important phase in the process.

Research and scientific and technological development play an important role in including water of reuse in the management of water resources. The study and the elaboration of quality standards are essential. Technological development is also necessary in order to best take advantage of the water from reuse, and to monitor each step of the water reuse process. Advances in technology should include a greater efficiency in treatment; the studies on the capacity of recharge of aquifers with reuse waters; efficiency of irrigation in agriculture with reuse waters; and human health problems related to treated residential water Control Technologies and rendering rainwater available for multiple uses could also be developed in studies and researches.

Monitoring of Water Resources

Water quality is not a static condition of an aquatic system, river, lake, dam or flooded area nor can it be defined by a single parameter. Water quality is a variable in space and in time and requires permanent monitoring to detect variation in space and in time. Physical, chemical and biological basic parameters supply essential indications of water quality and its variability. In Brazil, considerable progress has been made in monitoring surface and ground water (Braga et al. 2006a, b). Advances and technological investments are needed in order to create a data base of adequate information on the quality of surface and ground water. What is required:

1. Real time monitoring of surface and ground water, with terminals made available to users (Fig. 11.3a,b).
2. Monitoring of quality and quantity of water in real time, with hydrometeorological stations is crucial.
3. The monitoring of quality and quantity of surface and ground water should be considered a "system of information" (Straškraba and Tundisi 2008; Tundisi et al. 2004).

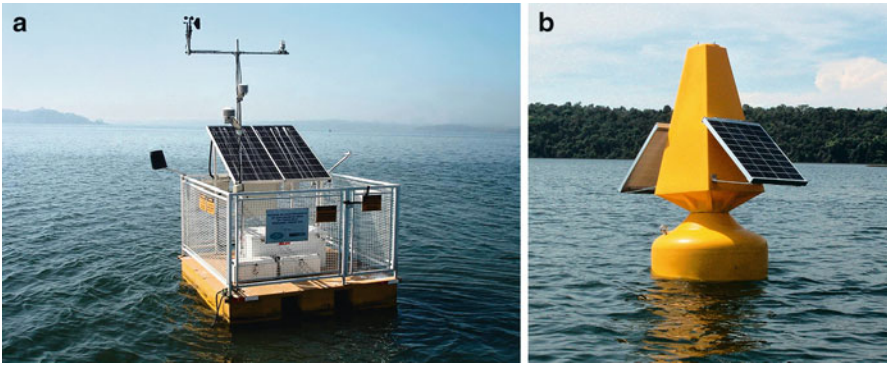

Fig. 11.3 (**a**,**b**). Monitoring in real time is one of the most important technological advances in the area of water management (Photograph: example of platform—IIEGA)

4. There is an urgent need for investments in the technological development of water quality sensors which will be able to lower the costs of implementation of the automatic stations.

The Role of Scientific Development and of Innovation in Management of Water Resources

Science, Technology and Innovation in Water Resources play a relevant role in the management process of hydrographic basins, surface and ground water. The integration of Science, Technology and Innovation with development processes and the incorporation of scientific knowledge and innovation in public policies, is crucial. Apart from the creation of scientific and technological networks of knowledge, it is extremely relevant to create "networks of competences", which will rapidly promote progress and innovations through the sharing of knowledge on processes and operating mechanisms with an integrated and interdisciplinary perspective (Bordage 2007).

The integration of the natural system with the socio economic system and the focus on researches that integrate these concepts will decisively advance the implementation of management of water resources. The integration of operating principles of water basins, quantity and quality of water, should be able to promote better and more objective integrated and predictive management capacities which are able to anticipate events and their consequences with regards to ecosystems, communities and species. On the other hand, it creates a basis of scientific and technological knowledge that should be the core of the management process at a hydrographic basin level, supplying the necessary scientific and technological information necessary for implementation. The integration of Science, Technology and Innovation in water resource management practices is therefore the essence of this dynamic and predictive approach. Results of researches should not only be communicated and published, they need to be utilized (Tundisi 2007–2009). International practice of water resource management and the implementation of International Centers of Research and Human Resource Qualification (Tundisi 2009) have demonstrated the effectiveness of this approach and the best qualification of managers and administers of water resources with a systemic and integrated vision. This process needs to further be developed in Brazil and "networks of competences" need to be implemented in the different hydrographic basins and in the country in order to meet the complex and urgent demands of management. "Innovation Data Bases" and new processes and Technologies should be implemented and the experiences need to be shared at a hydrographic basin level.

As an example, the significant progress of water management in the European Union is evident following the establishment of the Water Framework Directive, that use these quality indexes in hydrographic basins of countries pertaining to the union.

The use of ecohydrological and ecotechnological concepts (Jorgensen et al. 2005; Zalewski 2006–2007; Straškraba and Tundisi 2008, AIIEGA/PMSP/SVMA 2009) promoted considerable progress to water resource management; and the cases of the Metropolitan Region of São Paulo (AIIEGA/PMSP/SVMA 2009) and of Bocaina, in the interior of São Paulo, are relevant examples of the use of innovation in management of quality and quantity of water in urban regions (Fig. 11.4a,b).

The intensive use of ground water for several multiple activities has increased in the last decades and there is an urgent need for the inclusion of quality and quantity monitoring as well as for territorial planning and water management of this important component of the hydrological cycle (Llamas and Martinez-Santos 2006).

In conclusion, the use of scientific knowledge and of innovation in the management of water resources and in the establishment of consolidated basis for the decision making is a strategic process, with long term consequences and impacts on the sustainability of the water resources and in the environmental and economic sustainability of Brazil.

Water Governance: From Theory to Practice in Water Resource Management

Management and sustainability of water resources are part of the same group. If the principles of good water management (effectiveness, efficiency, coherence, transparency, control capacity and public participation) are all rigorously followed, sustainability of water resources will be guaranteed and maintained.

The hydrogeographic frontiers, in other words, hydrographic basins, offer opportunities for a decentralized and modern management of the water resources. This management is not a simple one, but the societies who share hydrographic basins need to have the conditions for implementing general rules supplied by the government (whose main tool of action is the Water Resources Law 1997) (Fig. 11.5). Aside from regulations, control and monitoring of pollution and contamination sources, billing for the use of water (Lanna and Braga 2006) and the polluter pay principle are all innovative perspectives, and increasingly effective, in management (ANA 2007).

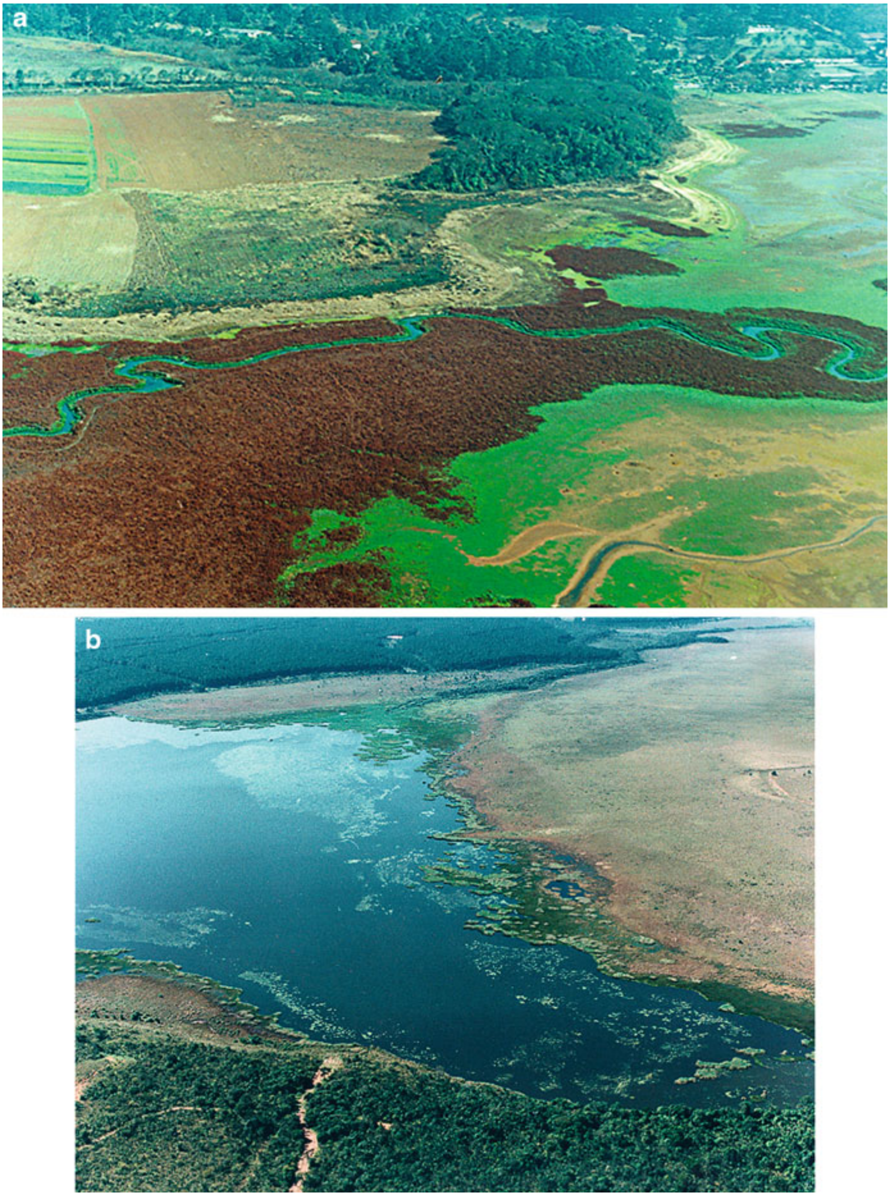

Fig. 11.4 (**a**,**b**). The use of flooded areas in the Metropolitan Region of São Paulo (as an example, the photo of the flooded area of Parelheiros/RMSP) can solve many hydrographic basin management problems (**a**); flooded area of the UHE Carlos Botelho Dam (Lobo/Broa) that works as a controlling system of the influx of nutrients and heavy metals to this dam (**b**). Photographs by J. G. Tundisi

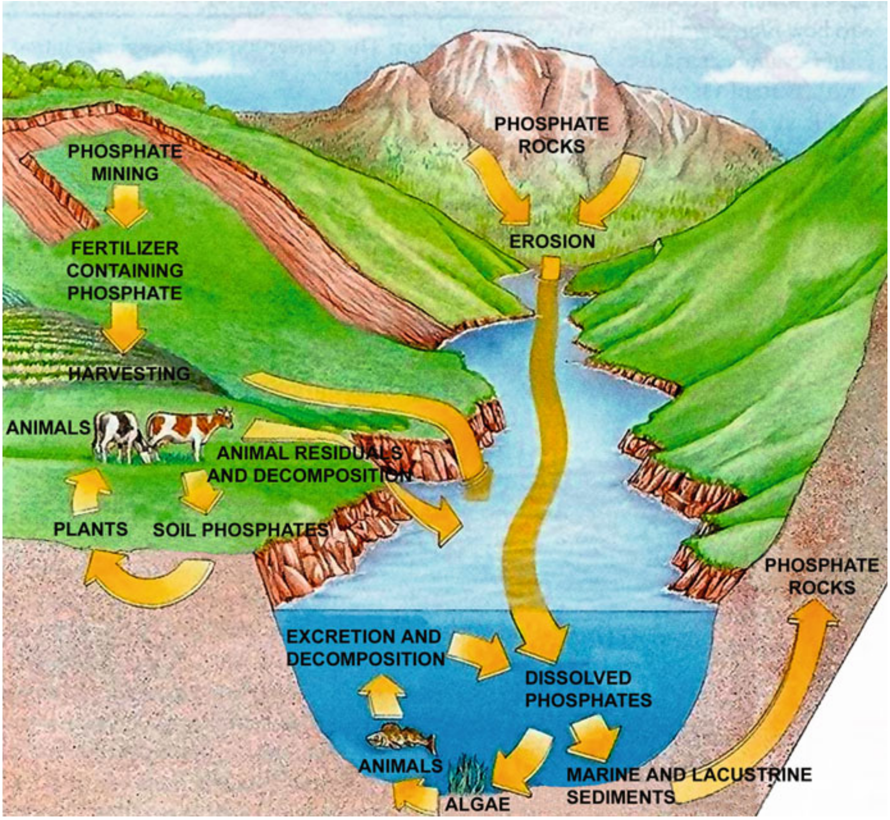

Fig. 11.5 Hydrographic Basins are "collectors of events" of human activities. The influences of these events can be observed in rivers, dams and sediments. *Source*: Raven et al. (1998)

The implementation of Hydrographic Basin Agencies, which are now being established in Brazil, and the technological basis at a hydrographic basin level, which will supply the scientific and technological support needed, will enable significant progresses in management. In addition, the use of methodologies and control tools with innovative techniques for reducing demand and contamination, together with criteria adopted on a basin level, are all additional opportunities and possibilities of favorable uses for water resource management.

The new management tools need to include differentiated functional processes such as: operational, organizational and constitutional, integrating legislation and regulation with scientific and technological applications and mechanisms that support the efforts (Tundisi 2006). Management of conflicts, integration of public and private sectors and the participation of users are all principles of management that, together with certified information, data bases and technological implementation, can be successful in promoting a better management of water resources. Also quite basic, is the use of ecological and mathematical models that integrate Power function, state and processes variables in lakes, reservoirs and rivers, with the objective

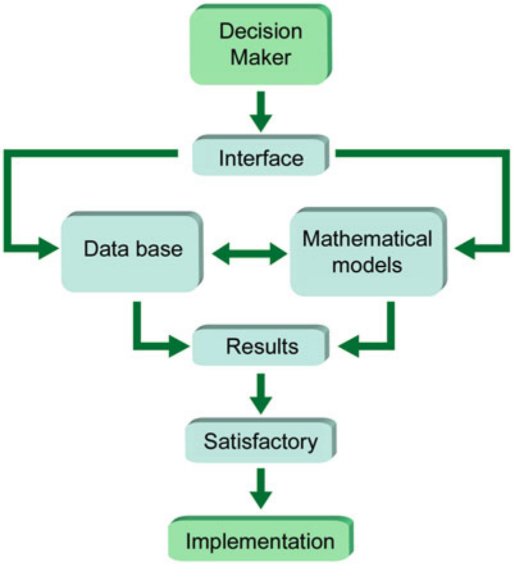

Fig. 11.6 Interaction between data bases, mathematical models and decision makers in the management of hydrographic basins. *Source*: Porto and Porto (2008)

of anticipating events and impacts, organize scenarios and prognostics and, consequently, promote new quantitative and qualitative solutions for the management of hydrographic basin and aquatic ecosystems. Porto and Porto (2008) show the use of mathematical models in the management of urban basins as one of the initiatives to advance methodologies in the integrated management (Fig. 11.6).

Conclusions and Recommendations

Efficient management of water resources requires a solid basis of Science, Technology and Innovation to consolidate it at a regional level as a national hydrographic basin. ANA's (2009) Survey Report clearly shows the need for advances in the area of water resource management, assessment of vulnerability, integration between multiple uses and their optimization, aside from investments in basic sanitation needed to decrease the impacts of direct disposal of sewages in waters of rivers, dams and coastal waters.

The making and implementation of Water Resource Plans that require actions at a regional, state and hydrographic basin level, needs data bases on availability/demand and quality of water; they also require the elaboration of future scenarios supported by quantitative data in order to asses impacts and suggest alternatives.

Including Science, Technology and Innovation in the context of Planning and in the Water Resources Plans is therefore, an essential requirement to promote the necessary progress in management one can therefore prepare a set of recommendations based on the problems here introduced and on the discussion developed within this report; they are:

Strategic Studies

Preparation of strategic studies requested from researchers, groups of researchers of research institutions should be increased. These studies should involve the diverse components of Science, Technology and Innovation relevant to the management of water resources. Both in the technological area as well as in the scientific area, strategic studies that take into consideration the different regional adversities at a hydrographic basin level; can effectively contribute towards promoting opportunities and alternatives for development.

Persistent Organic Pollutants (POPS)

Future researches agendas should include an assessment and a quantification of organic substances dissolved in water, especially in urban areas.

Regional Data Bases

Regional data bases, organized in a way that they can be accessed for different uses, and set as a basic platform for management can be obtained from researches and innovative works developed in the different Universities and Research institutes. Data bases created per hydrographic basins are considered to be a much needed and significant progress.

Contamination and Eutrophication

Even if we take into consideration the great advances in scientific knowledge and in the qualification and quantification of eutrophication, further in depth studies are needed. We also need to increase our capacity of anticipating events and promoting new possibilities for using bioindicators at a regional level. Studies on toxicology and on ecotoxicology related to pesticides, herbicides and the aquatic fauna and flora in natural systems, need to be intensified.

Valuing Water Resources

Valuing environmental services of lakes, dams, rivers and other flooded areas is a priority. This valuation can result in new opportunities and alternatives of management, supported by economic values, aside from integrating this vision into the economic market of water. Valuing can also have an important consequence in the management of hydrographic basins, in the protection of natural sources for supply and in the selection of development alternatives based on conservation, multiple use and rational uses of water (AIIEGA/PMSP/SVMA 2009).

Ecological and Mathematical Models

There is a strong need for investments in using and developing ecological models: to improve our predictive capacity in the area of water resources; to implement dynamic models in different ecosystems (dams, rivers and artificial lakes), and to improve the capacity of an integrated management and the creation of possible scenarios.

Ground Waters

For the management of ground water, investments are needed to identify the origins and sources of contamination and for permanent monitoring of water quality. The integration of the studies and monitoring of ground water in the 'vis-a-vis' Territorial Planning, with the different uses of the soil and contamination, is yet another essential component of research and management.

Water Governance

Management of water is a complex set of interactions between availability of resources, economy and the population. The inclusion of science and technology at a hydrographic basin level (data bases, scientific information and technological development, technological innovations) can promote crucial opportunities for an integrated and predictive management at an ecosystem level: the new paradigm of water resource management of the twenty-first century.

Global Climate Changes and Water Resources

The lines of research in this area are extensive. There is a need to improve knowledge between climatology and the functioning of lakes, rivers and dams from a dynamic point of view; prevent the growing impacts of eutrophication with the increase of water temperature of lakes and dams; integrate studies of events and climatic phenomena in the plans and the management planning programs of water basins.

Monitoring of Quantity and Quality of Waters

The real time monitoring of surface and ground water needs to be expanded to include critical hydrographic basins. The joint monitoring of quality and quantity of waters is crucial for an adequate assessment of availability/demand and of quality of water, in order to implement regional data bases at a hydrographic basin level.

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Chapter 12
Climate Change and Water Resources

José A. Marengo, Javier Tomasella, and Carlos A. Nobre

Abstract This report presents a general vision of the availability of water in Brazil within the context of climate variability and change. Despite Brazil having great water availability, its distribution among the regions is very uneven. The current situation, in terms of scarcity, is mainly due to inadequate planning of land and water use associated to economic growth: as an example, the Southeast area of Brazil, which has great water availability, is affected by lack of water due to uncontrolled urbanization growth. Water availability in Brazil is directly related to the climate, especially during the months of summer. Delays in the start of rainy seasons can affect agriculture and the hydroelectric power generation; and the occurrence of severe floods and droughts have caused great impacts in the economy and to the population. This can be seen, for example, in the case of the drought in Amazonia in 2005 and the floods of 2009 in Amazonia. Brazil is vulnerable to these climatic anomalies and will be vulnerable to the changes projected on rainfall patterns and on extremes weather patterns due to climatic change. Changes in patterns and in precipitation regimes could also affect river flows; current studies indicate that the most affected river will be the São Francisco River, where the reduction in rainfall will result in a drastic decrease of discharge and consequently will severely impact irrigation and the hydroelectric power generation. Without a doubt, the uncertainties of the future projected scenarios always need to be taken into consideration. Actions focused on adaptation and mitigation is urgent, as are monitoring plans for water resources in order to assess climatic risks. Comprehensive research on climatic change and its impacts on water resources is extremely necessary. Water resources management should also consider the climate change projections and uncertainties in the implementation of water policies and regulations.

Keywords Agriculture • Governance • Irrigation • Public policies • Scarcity • Water resources

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Introduction

Brazil occupies a privileged position in the world with regards to availability of water resources, with about 12 % of the world's water, which corresponds to 1.5 million $m^3 s^{-1}$ (Shiklomanov et al. 2000). Yet, part of the Brazilian population lives without the benefit of this resource. Brazilian freshwater reserves are not evenly distributed throughout the country, since 80 % of them are found in the Amazonian region. The Northeastern semi-arid region, even with the inclusion of part of the São Francisco river basin, possesses only 4 % of the country's water resources but is home to 35 % of the Brazilian population, mostly composed by low income families. The humid regions of the South and the Southeast, where 60 % of the population lives, had in the past ample reserves of water resources. Currently these areas run the risk of local or generalized water scarcity due to economic growth and accelerated urbanization. This situation will only be tackled with the improvement of management of water quantity and quality.

Water availability in Brazil greatly depends upon the climate and the climatic variations over time. Heavy rainfall, especially during summer can be associated to floods and have direct impacts on the population, yet in seasonal time scales, a delay in the start of the rainy season can cause tremendous impacts to agriculture and to hydroelectric power generation. The presence of droughts in several different basins in Brazil, on annual level, are examples of the inter-annual variability of the climate associated to the El Niño or La Niña in the Tropical Atlantic to the North and South of the equatorial line, that can generate climatic anomalies that lead to great droughts such as the ones of 1877, 1983 and 1998 in the Northeast, 2004–2006 in the South of Brazil, 2001 in West Central and Southeastern Brazil, and in 1926, 1983, 1998 and 2005 in Amazonia (Marengo et al. 2008a, b; Cox et al. 2008). Additionally, the risk deriving from climate change, whether natural or of anthropogenic origin has caused great concern within the scientific community and the government, with the water resource sector being one of the most affected areas, both with regards to quantity as with regards to quality of water.

The Fourth Scientific Report by IPCC AR4 (Trenberth et al. 2007; Meehl et al. 2007) and the Climate Report by INPE (Marengo et al. 2007; Ambrizzi et al. 2007) present evidences of climate changes, that can significantly affect water availability in several regions, with severe impacts to total rainfall and on the hydrometereological extremes by the end of the twenty-first century. Brazil is vulnerable to the current climate variability, as can be seen by the recent intense rainfall during the Summer of 2008/2009 in the states of the South and Southeast of Brazil and the historical flood in Amazonia and in the North of the Northeast, that have caused significant financial losses of hundreds of millions of reais, more than 200 deaths and millions homeless. Analysis of rainfall databases over the last 50 years indicate that extreme events of rainfall are more and more frequent and intense and that the projections from global and regional models for the future, indicate that this trend will probably continue and become even more intensified. Therefore, Brazil is also vulnerable to climate changes projected for the future, especially with regards to climate extremes. The knowledge on possible future climatic-hydrological scenarios and their uncertainties can assist us in estimating water demands for the future and define environmental policies for use and management of water.

In this study, we assess the state-of-the-art in knowledge on climate change and the impacts of the availability of water in the future, taking into consideration studies on long-term tendencies of the last 50 years and the projections made by climatic models up until the end of the twenty-first century. For further information, we recommend the reader to refer to the Reports of the Work Groups 1 and 2 of IPCC AR4 (www.ipcc.ch), the Climate Report by INPE (www.cptec.inpe.br/mudancas_climaticas) and IPCC's Report on Climate Changes and Water (Bates et al. 2008).

Current Problems

In Brazil, the most vulnerable region to the risk of climate variability and change and to an increase in aridity and subsequent desertification due to climate changes is the Northeast (Salazar et al. 2007). Over 70 % of the cities of the northeastern semi-arid region, with a population of more than 5000 inhabitants, may suffer a crisis by 2025 with regards to water supply for human consumption. Supply problems will most likely affect about 41 million inhabitants of the semi-arid region and its surroundings, as per projections from researchers of the National Water Agency (ANA), who estimated population growth and water demand in approximately 1300 cities that belong to nine states of the Northeast and the northern part of Minas Gerais (ANA 2005).

The situation in Amazonia is worrisome. In 2005, a severe drought—the worst in the last 103 years, only comparable to the drought of 1962–1963—hit the west and the southwest of Amazonia. Some large rivers from the Amazon basin decreased their tidal level up to about 6 cm per day. Millions of fish died and rotted in the beds of the tributaries of the Amazon River that served as a source of water, food and transport to riverside communities (Marengo et al. 2008a, b). The possibilities of periods of intense droughts occurring in the Amazonian region can surpass the current 5 % (which represents one severe drought in every 20 years), to 50 % by 2030 and even 90 % by 2100 (Cox et al. 2008).

On the other side of the pendulum of climatic extremes, Amazonia has been facing a flood of historical dimensions, greater than the historical maximums registered in the port of Manaus in the last 100 years, greater than the Record levels ever registered of 1953. According to the Geological Service of Brazil, 1953 marked Manaus' history as the period of the worse flood of the capital. At the time, the level of the Negro River reached 29.68 m and it is anticipated that within the next months, this level will surpass 30 m. These extremes are repeated in the North of the Northeast region, causing considerable economic damages and a strong social impact. In the South and Southeast regions of Brazil, the systematic increases of rain can also be seen through hydrological data and via rainfall extremes (Marengo et al. 2009). The intense rainfall that hit parts of Santa Catarina, especially in the

Valley of the Itajaí-açu River during November 22–25 of 2008, was caused by an atmospheric blocking in the Atlantic Ocean. The rains affect the coastal strip of the State of Santa Catarina. In several cities on the coast of this state, daily rainfalls exceeding 200 mm were registered in Blumenau, Balneário Camboriú, São Francisco do Sul, Itapoá and Biguaçu. Official data from EPAGRI/CIRAM indicated that the rains in November were historical records in the cities of Itajaí, Blumenau, Joinville, Indaial and Florianópolis. The volumes of the rain mentioned, are equivalent to 50–70 % of the total expected for the entire year and registered over a period of only 1 month.

The intense rainfall and floods and subsequent avalanches affect 1.5 million people, with 123 deaths and more than 69,000 people who lost their homes (INPE 2008).

The majority of the anomalous rains in the Southeastern South America, including those from Santa Catarina are being associated to the simultaneous occurrence of intense weather events related to the El Niño phenomena such as those from 1911, 1957, 1983, 1987, 1998, among several others. However, intense rainfall, even if in a smaller special scale, can occur regardless of the large scale influence of El Niño, as occurred in 1984 and in 2008. The floods from 1983, which caused damages of about US$ 1.1 billion in the entire state of Santa Catarina, reached a peak level of the Itajaí-açu River of 15.34 m. These were immediately followed by the floods of 1984, with a peak level of 15.46 m. In February of 1987 the phenomenon El Niño caused floods in 15 municipalities of Santa Catarina and in 1997 caused additional floods of great proportions also in Santa Catarina during the months of January and October. During the floods of January, 35 municipalities were affected and in October the floods hit 37 cities.

Water Resources in the Context of Climate Change

For several specialists, the water crises is the result of a set of environmental problems, made worse by economic issues and by lack of development (Gleick 2000). With this vision in mind, it is a mistake to deal with the issues related to water resources, exclusively as if it were an issue of lack of availability in the face of an increase of demand. It is crucial to view the problem as an issue related to management of resources.

There are several causes that explain water resources scarcity (Tundisi 2008):

1. Intense urbanization, increasing the demand for water supply and water for economic and social development, increasing discharge of contaminated water resources.
2. Water stress and scarcity in several regions of the planet due to alteration in availability and increase in demand.
3. Poor, and in critical stage of infrastructure in several urban areas with losses of up to 30 % in the networks following water treatment.
4. Problems of stress and scarcity due to global warming and climate change, with extreme hydrological events increasing human population vulnerability and compromising food security (intense rainfall and periods of intense droughts).

5. Problems in the lack of coordination and lack of consistent actions in the management of water resources and in environmental sustainability.

In addition to these problems, we can add the inadequate use of land in suburban and rural areas. The floods that hit Santa Catarina in 2008 resulted in dramatic characteristics in terms of economic damages and loss of human life caused by landslides from slopes, whose outbreak is strongly accelerated by the removal of natural vegetation.

The advancement of desertification in several areas of the semiarid of the country, as well as in Rio Grande do Sul are clear examples of how the inadequate management of the land increases the impacts associated to water deficiency.

Amazonia, which is the region of the country that presents the highest level of preservation of water resources, is dramatically being affected by the increase of livestock ranching and agriculture along the so called “deforestation arc”. Taking into account that these affected areas form the headwaters of rivers such as Tocantins, Xingu and Tapajós, the occupation of this region without any concern for the environment will result in consequences in large areas downstream of the headwaters of these rivers due to the transfer of the impacts. Very little is known about how these actions today will affect the sediment load of these rivers or their hydrological regime, which can severely affect activities such as navigation, fishing and the generation of electricity.

Therefore, the impact of climate change on water resources cannot be dealt with without considering all the current uses of the resources; and inevitably these changes will increase all the problems preciously identified.

The solution to these problems requires an institutional approach, not only locally, but also regionally and globally. Therefore, the greatest challenge when facing the issue of water resources, with regards to climate change, relates to the need of have one unique institutional framework which allows for an integrated management of the water resources. The provisions introduced in the Water Act of 1995 represent a tremendous breakthrough in the integrated management of water resources.

However, many of these principles have not been properly incorporated in the planning of water resources and many of the provision of this Law have still not rendered a practical result.

A typical example of this is the implementation of basin committees in several hydrographic basins of the country, which is still very incipient. At the same time, it is necessary to analyze whether the legal framework is adequate considering the global nature of water security, especially faced by climate change, and should be dealt with on a global scale which surpasses all the political boundaries. Up until recently, the biggest problems with regards to the issue of climate change, referred to the lack of assessment of the impacts, possible actions for its mitigation and adaptation to these impacts. The lack of a coordinated action at an institutional level resulted in a majority of studies being carried out in a sector manner, without the necessary systematic approach required by the water problem.

Present and Future Climate

The continent has already experienced a series of radical occurrences in the last years such as: torrential rains in Venezuela and in the southeast of South America, floods in the pampas of Argentina, droughts in Amazonia and in the South of Brazil, floods in Amazonia and in the North of the Northeast, hailstorms in Bolivia, a record season of hurricanes in the Caribbean and, recently in 2009, drought in the North of Argentina and in the South of Brazil and the great floods in Amazonia and in the Northeast. At the same time, the rains decreased in Chile, in the South of Peru and in the Southeast of Argentina.

With the increase of temperatures already registered (1 °C in Central America and in South America in a century, with a world average of 0.74 °C), the Andean Glaciers are receding and can compromise water availability destined for consumption and for the generation of electricity, worsening the problem for the future, which could become chronic if measures are not taken, states the report of IPCC GT2 for Latina America (Magrin et al. 2007). Global warming is drying out lakes in mountains and swamps in the Andes and compromising water supply to great Latin American countries such as La Paz, Bogotá and Quito (Vergara et al. 2007). The melting of glaciers, also caused by global warming can jeopardize water supply to Quito and the generation of hydroelectric energy to Peru. The glacier from Chacaltaya in Bolivia can disappear completely within the next 20–30 years and several other Andean glaciers can disappear in the twenty-first century, resulting in important consequences to the availability of water, to the generation of energy and to the integrity of the ecosystems (Francou et al. 2003).

With regards to rainfall, one can observe a trend already detected in previous studies of IPCC AR4 (Trenberth et al. 2007), of an increase of rainfall of up to 30 % per decade in the Prata Basin and in some isolated areas of the Northeast of the country. In Amazonia, a specific trend of increase or decrease of rainfall due to deforestation cannot be determined, showing instead a trend of more contrasting inter-decadal variations between the North and the South of Brazil. In the Northeast, the observed trends also suggest an inter-annual variability associated to El Niño and to the sea surface temperature (SST) in the Tropical Atlantic, as well as a decadal scale trend associated to the changes in the meridional position of the Intertropical Convergence Zone (ITCZ). Regionally, since 1950 an increase of the total and of the extremes of rain in the South and in parts of the Southeast of Brazil, in the Paraná-Prata basin, have been observed, consistent to the similar trends of other countries of the Southeast of South America. In the Southeast, the total annual rainfall does not seem to have suffered any noticeable modifications in the last 50 years.

The projections of changes in the regimes and distribution of rains, obtained from global models of IPCC AR4 for warmer climates in the future, are not conclusive and the uncertainties are still many because they depend upon the models and the regions being considered. In Amazonia and in the Northeast, even though some global climate models of IPCCC AR4 present drastic reductions of rainfall, other models indicate an increase of rainfall. On the other hand, the averages of all models indicate a greater probability of reduction of rainfall in regions such as eastern Amazonia and Northeast Brazil, as a result of global warming (Fig. 12.1a). The IPCC AR4 (Meehl et al. 2007) indicated a reduction of rainfall in the North and the Northeast of Brazil during the months of winter (JJA), which can affect the rainfall in the eastern Amazonia and Northeast, Brazil that has its peak rainy season during this time of the year. According to reports from IPCC for Latin America (Magrin et al. 2007) and from INPE (Marengo et al. 2007; Ambrizzi et al. 2007), the semiarid region will tend to become more arid. The frequency and intensity of droughts will increase and water resource availability will be reduced. The projections for the future of climate models also suggest an increase of rainfall for the Southern Brazil and in the Prata basin and for the west of Amazonia by the end of the twenty-first century. This increase might possibly present itself in the form of extreme rains occurring more intensely and frequently (Fig. 12.1b), which is already being observed since (Marengo et al. 2008a, b).

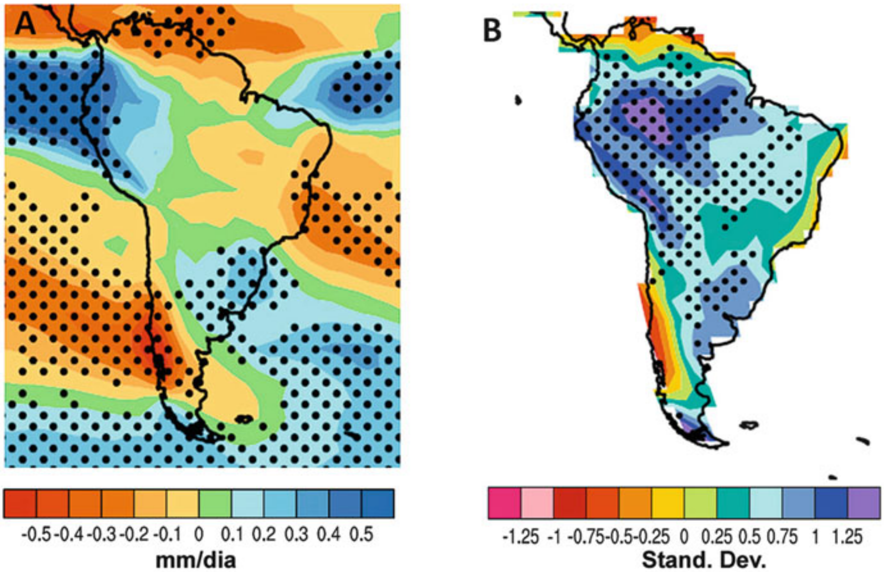

Fig. 12.1 (**a**) Changes in annual rainfall (%) and (**b**) R10 index or number of days with rainfall above 10 mm (by means of standard deviations) (average of 15 IPCC AR4 global models) for the period of 2080–2099 of the scenario of greenhouse gas emission A1B for the average of 1900–1998. Areas with dots show regions where at least 60 % of the models showed the same sign (Bates et al. 2008)

Current Hydrology and Future Projections

With regard to river flows, the observed trends of rainfall clearly reflected the trend of rain, with an evident increase of flows in the Paraná River and in other rivers of the Southeast of South America. In Amazonia, in the Pantanal and in the Northeast Brazil, long term systematic trends were not observed with regards to dry spells or rainy conditions; most importantly however, were the inter-annual and inter-decadal variations associated to the natural variability of the climate in the same time scale of the variability of inter-decadal phenomena of the Pacific Ocean and the Tropical Atlantic ocean. River flow analysis in South America and in Brazil (Milly et al. 2005) indicated increases between 2 and 30 % in the Paraná basin and in the neighboring regions of the Southeast of South America, consistent to the analysis of the trends of rain in the region. Important trends were not observed in the flows of the rivers of Amazonia or in the São Francisco River basin. In the west coast of Peru, the positive trends of rainfall can be explained due to the extremely high quantity of rains and flows during the years of El Niño in 1972, 1983, 1986 and 1998 that clearly affect these trends.

Milly et al. (2005) analyzed the components of the flows of the rivers of several IPCC AR4 models for the future, compared to the present. Figure 12.2a,b shows that the IPCC AR4 (Fig. 12.2a) models adequately represent the growing trends observed in the Paraná-Prata basin. By the end of the twenty-first century, the IPCC AR4 models indicate reductions in the flows of the São Francisco, Parnaíba, Tocantins and Xingu Rivers, and in other rivers in the East of Amazonia, as well as in Central Chile. On the other hand, the models also indicate increases of flows in rivers in the West

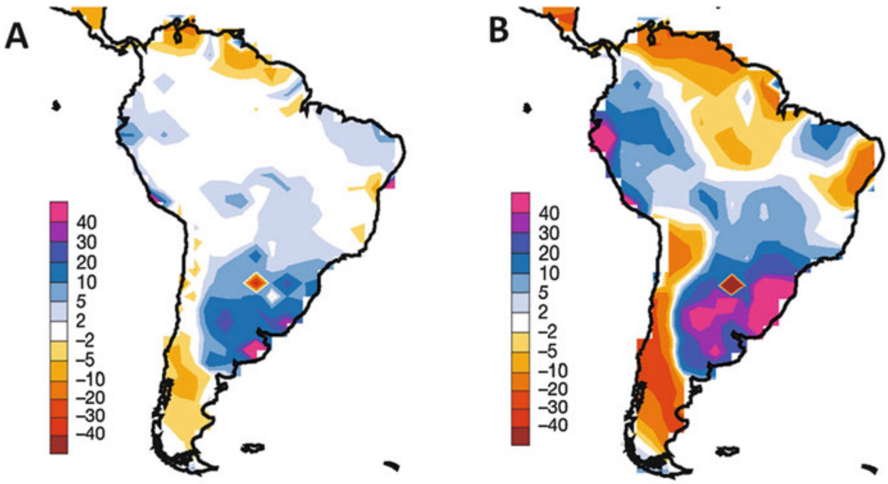

Fig. 12.2 (**a**) Relative change (%) of flows of rivers in South America (average of 9 IPCC AR4 global models) for the period of 1971–2000 for the average of 1900–1970 of the climate simulation of the twentieth century (20C3M) from IPCC; (**b**) Relative change (%) of the flows of rivers in South America (average of 9 IPCC AR4 global models) for the period of 2041–2060 of the scenario A1B of the average of 1900–1988 (turn 20C3M) (Milly et al. 2005)

Coast of South America, near Peru-Ecuador and in the Paraná-Prata basin. These projections are very important, because the alterations of flows can change the frequency of floods and this can cause damages to the ecosystems and affect the production of food, transportation and the generation of energy. The increases in flows are consistent to the increases of rainfall in the future (Meehl et al. 2007).

Hydrometeorological Climatic Extremes

In the Southeast and in the South of Brazil, and intense increase in rainfall has been observed in the last 50 years, as shown in Fig. 12.2a (Marengo et al. 2009). They were identified positive trends of systematic increases of rain and of other rainfall extremes in the subtropical region in the South and in the Northeast of Brazil. These authors indicated that Southeastern South America has shown, since 1940, systematic increases in the frequency of intense rains of up to almost 58 % every 100 years. There was indication that in São Paulo, more occurrences of extreme rains are see during the El Niño, which indicates that these States are sensitive to the intensity of the South-Atlantic Convergence Zone (SACZ).

Some authors investigated the trends of extreme rains in the southeast of South America for the period of 1960–2000 and encountered trends for more humid conditions in the South of Brazil, Paraguay, Uruguay and in the North and Central Argentina. They also noticed that the Southeastern South America experienced an increase in the intensity and in the frequency of days with intense rains, which coincides with the works of Groissman et al. (2005) for the same region.

Intense occurrences of rains in autumn can be the cause of the great flows of the Paraná River, in the Argentinean Pampas. It was showed that in São Paulo, on an inter-annual scale, the number of occurrences of extreme rains shows a correlation with anomalies of SST in the Tropical Atlantic and in the Southeast of the Atlantic, near the coast of São Paulo. The control performed by the South Atlantic Convergence Zone (SACZ) and by the South American Low-Level Jet (SALLJ), on and inter-annual and intra-seasonal scale, can be observed in the frequency of occurrences of intense rainfalls associated to the presence of the SACZ and the SALLJ, that on average, indicate a greater frequency of intense rains in the southeast of Brazil, when the SALLJ is intense and the SACZ is weaker and relocated to the south of the Northeast region. Different authors defined extreme occurrence of rain following different methodologies and using similar of superior values of percentages (95° C), which makes comparison of results difficult. In the South of Brazil, It was identified a slight trend of increase in the number of occurrences of extreme rains, with a greater frequency in years such as 1993–1994 e 1997–1998, which were the years of the El Niño.

Trends were analyzed in annual extremes of rain and concluded that they appear to be similar to those of total accumulated rain, in other words, positive in the South of Brazil, Paraguay and Uruguay, and in the central north of Argentina. These extremes identified positive trends in the number of days with intense and very intense rains (R20 mm) concentrated in short periods of time and in quantities of rain found in occurrences which are indicators of rains that cause floods during the period of 1961–2000. These trends suggest an increase in the frequency and intensity of occurrences of rain in the southeast of South America, while the lack of data in the tropical region does not allow for a more comprehensive analysis of the extremes in this part of the continent.

The projections of extremes, according to IPCC AR4 (Meehl et al. 2007, Bates et al. 2008), indicate increases in the frequency of extreme rain for all of Brazil, mainly in the west of Amazonia, south and southeastern of Brazil. For the period of 2080–2099, in comparison to the previous period (1980–1999), within the scenario of greenhouse gas emission A1B, extreme occurrences of intense rain show an increase in the frequency and in the contribution of very rainy days in the west of Amazonia, while in the Eastern Amazonia and in Northeast Brazil the probability is of an increase in the frequency of consecutive dry days, which can also be observed for Southeastern Brazil. Recent studies (Marengo et al. 2009) suggest in fact, that the possible scenario of increase of rain in the South of Brazil, projected for the end of the twenty-first century, can occur in the form of more intense and frequent extremes of rains (Fig. 12.3). The west of Amazonia may experience an increase in the frequency of extreme rains by 2100, which may lead to problems of erosion and floods in this region. However, the lack of trustworthy hydrological information in this region, does not allow us to ensure the certainty of the simulated trends for this current projection.

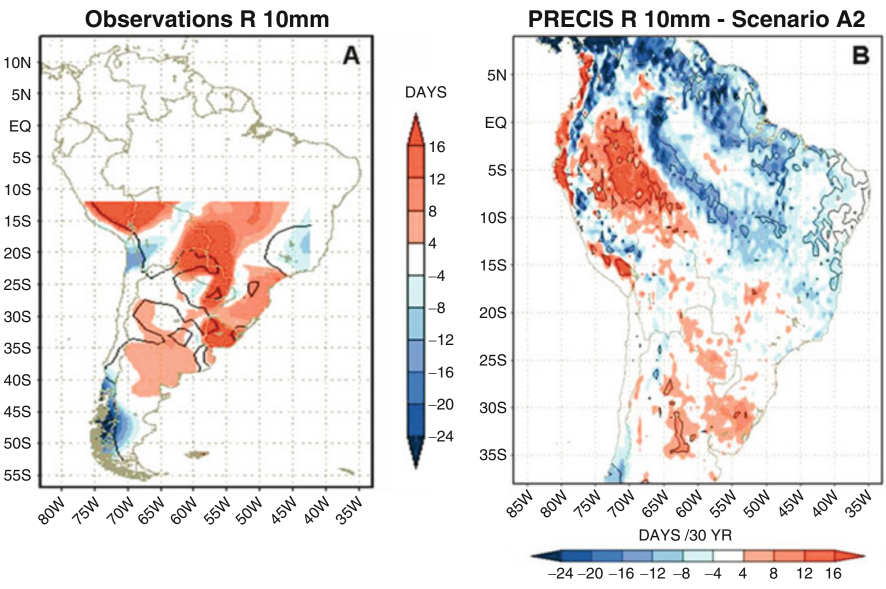

Fig. 12.3 Trends of extreme rains represented by the R10 index (number of days with rain above 10 mm), (**a**) based on information for the period of 1951–2000; and (**b**) projected by the regional model HadRM3P for the period of 2071–2100 relating to 1961–1990, scenario A2 of high emissions (*Source*: Marengo et al. 2009)

Impact and Vulnerability Studies in Brazil

The majority of studies in Brazil have been focused on the impacts on surface water resources, with emphasis on the issues related to hydroelectricity and agriculture. As an example, we can highlight three studies that generally summarize the existing studies in terms of impacts of climate changes on water resources. They are:

1) Recent studies of the Sustainable Development Foundation (Salati et al. 2009) indicate that the climate scenario will cause a reduction of the water surplus in all the large Brazilian basins (Table 12.1). This study utilized the average of 15 climatic models from IPCC for the scenarios B1 and A2 and the HadRM3P regional model for the same scenarios. The study used the Thornthwaite-Mather Water Balance model for eight hydrographic regions of Brazil together with calibrated water balance, so that the water surplus generated in the period of 1960–1990 would be compatible to the flow values measured by the ANA network station.

Table 12.1 shows that the reduction of water surplus is not significant in the Northeast region of Brazil and in particular in the São Francisco River basin. The study also foresees reductions in the Tocantins River basin.

Taking into consideration the enormous vulnerability to water scarcity of the Northeast region, it becomes evident that, in the agricultural point of view, one can expect severe impacts of climate change in this region.

Table 12.1 Reduction of water surplus the Northeast region of Brazil, particularly in the São Francisco River basin

		Average models 2°×2° lat/long											
		Period 2011–2100						HadRM3P 50 km×50 km					
		B1			A1			B2			A2		
Hydrographic basin	1961–1990 (%)	11–40 (%)	41–70 (%)	71–100 (%)	11–40 (%)	41–70 (%)	71–100 (%)	11–40 (%)	41–70 (%)	71–100 (%)	11–40 (%)	41–70 (%)	71–100 (%)
Tocantins	100	83	77	73	84	73	63	72	67	54	73	55	47
Amazonas	100	88	82	80	89	80	73	93	84	75	93	73	70
Paraguay	100	68	60	59	73	54	40	81	91	92	90	85	147
Parnaíba	100	69	59	56	70	54	47	32	19	14	34	13	10
São Francisco	100	73	57	43	72	46	30	38	42	47	43	45	53
Occidental NE Atlantic	100	88	87	86	92	85	80	72	62	59	71	52	47
South region	100	95	93	92	95	90	86	111	109	116	109	101	107
Paraná	100	80	74	67	83	67	47	84	84	93	94	88	110

2) In the area of agriculture, recent studies from EMBRAPA (2008) estimated that global warming shall cause losses of about R$ 7.4 billion in 2020, which could reach R$ 14 billion in 2070. EMBRAPA's study indicated that the cultivation of soybeans will be the most affected. In the worse scenario, losses could reach 40 % by 2070, leading to a loss of up to R$ 7.6 billion. In EMBRAPA's study, the coffee produced in Southeastern Brazil will be severely affected due to the increases of risks, but may present an increase in production in the south of the country. Corn, rice, beans, cotton and sunflower will suffer a considerable reduction in the low risk area of the Northeast, with a significant decrease in production. The cassava will have an overall gain of area of low risk, but should suffer serious losses in the Northeast. The cultivation of sugar cane could double in the next decades.
3) One of COPPE's studies should be mentioned (Schaeffer et al. 2008), that focused on the issue of hydroelectricity. This study predicted falls in the production of energy which varied between 1 % and 2.2 % (average of the national electric park) in the A2 and B2 scenario respectively, with, once again, the São Francisco River basin being the most affected, with losses between 4.3 and 7.7 %.
4) In a more detailed research, however, with a regional coverage, Tomasella et al. (2009) presented an analysis of the impacts of climate changes for the Tocantins River basin and all of its main sub-basins, for scenery A1B, using model ETA (resolution 40 km) with boundary conditions from the global model HasCM3. The study concluded that, in terms of monthly averages, the reduction for the scenario 2080–2090 is of about 30 %, but that these reductions could reach up to 60 % in drought seasons. In general, this study showed a displacement of the duration curves for the minimums, which indicates that there is a probability of a reduction of flows for almost all the probability scales. In addition, the impacts are greater in the Araguaia River basin, whose draining area is located in crystalline soils. One important aspect of this study is that it indicates that the occurrence of water deficiency is not the same all year long and that the impact can vary according to the characteristics of the hydrographic basin.

Although these studies are concentrated in areas and activities of great economic impact for the country, they often lack the level of details necessary for planners to have the technical support needed for the elaboration of regional plans for mitigation. This occurs due to technical and scientific constraints which pervade the lack of detailing within the climate scenario, within the specification of uncertainties and within the limitation of the mathematical models used in the assessment of the impact.

Another problem about the existing studies on impact is its sectorial nature. The different uses of water, whether or not consultants, are strongly interdependent. For example, the expansion of an irrigated area affects the generation of energy downstream. Therefore, the lack of an integration of the focus on the use of water resources does not allow for an assessment, in terms of climate changes, of whether the route of changes, summed to the increase in water demand due to population growth, will or will not have a synergetic effect among the possible future uses of the resource.

And lastly, there are considerable limitation of scientific knowledge with regards to establishing functional relationships between hydrology, land, climate and vegetation (ecohydrology) in the main ecosystems of the country. This knowledge is crucial not only to determine spatial distribution of ecological communities and their physical structure as well as their species structure, in a way of better quantifying the natural resources of the country, but also in order to provide theoretical and experimental support to the future scenarios such as the "savannization" of Amazonia (Oyama and Nobre 2003) or of "aridization" of the Northeast (Salazar et al. 2007). These functional relationships between the vegetation and the water regime are completely unknown in the seasonal flooded ecosystems of the country, such as the extensive areas of the Pantanal or of the Amazonian Plain.

It is therefore necessary to improve these studies not only with regards to uncertainties, but also with regards the approach towards different studies.

Ground Water

The increase in temperature due to climate changes have direct effects on the hydrological cycle, altering the total amount of rainfall, its temporal and spatial distribution (frequency of droughts and floods), affecting therefore the hydrological processes such as flows and infiltration. These changes will affect water storage in the ground and consequently, the recharge of aquifers. Therefore, within this context, it is obvious that climate change is affecting temporal and spatial levels of aquifers, with consequences not only to human supply, but also affecting the capacity of regularization of large rivers (with consequences to all water uses, consultative or not) or even indirectly, affecting activities like construction and mining.

As per ANA's report (2005), the flow of recharge of renewable ground water reserves in the country are of about 42,000 $m^3 s^{-1}$ or 24 % of the mean flow of the rivers of national territory and 49 % of the flow in dry seasons. Considering the usable reserves as being equal to 20 % of the renewable resources, one has about 8400 $m^3 s^{-1}$ of ground water resource availability (usable reserve) total, in the country. This estimate corresponds to all aquifer systems of the country, including those of a smaller hydro geological potential as for example, those found in crystalline grounds.

The country possesses important aquifer systems with good distribution in hydrographic regions and with good water potential. The majority of these aquifers is of the porous type and is found in sedimentary basins, which occupy approximately 48 % of the national territory. The main aquifer systems of the country, totals a renewable reserve of 20,000 $m^3 s^{-1}$, with about 4100 $m^3 s^{-1}$, estimated as ground water availability (usable reserve).

One can argue that in a country with such an abundance of surface water, the ground water reserves have a relatively limited reach. However, in several regions and urban centers of the country, ground water represents the main source of water, being used for several purposes such as human supply, irrigation, industry and leisure. Aquifers constitute, due to their large spatial extent (which eliminates the need for complex supply and distribution systems like in the cases of fountains located in rivers and lakes) together with their natural capacity of debugging, the main source of water supply in many regions of Brazil.

This deficiency arises, partly due to the lack of hydro geological studies.

The existing studies, usually limited to the sedimentary areas of the country, are of a limited regional scale and are usually outdated articles (ANA 2005).

Conclusions

As was previously discussed, one still does not possess a clear picture of the possible impacts of climate change on spatial and temporal distribution of the water resources in the continent. The uncertainties still represent obstacles for the operational planning and the management of the water resources, but, even so, this cannot be used to avoid immediate actions focused on adaptation.

One of the first actions would to establish research programs and monitoring to assess the risks related to climate change. Regions like the Northeast and the southeast central west are highly vulnerable, due to their dependency on electric energy. In these regions, climate change (especially in the form of an increase of air temperature) can increase to the risk already imposed by the growing population, urbanization, industrialization, and the changes to the use of land associated to agriculture and cattle farming. In Amazonia, however, the problems are associated to the possible loss of biodiversity and to the impacts to the hydrological cycle.

Scientific evidence indicates the fact that climate changes represent a serious risk to water resources in Brazil. Not only do the future climate changes represent risks, but also the climate variability. As examples, we have the droughts in Amazonia, Northeast, South and Southeast in Brazil in the last 10 years, the extremes of rains in the South and Southeast of Brazil during the recent summer seasons and the floods in Amazonia 2009, of which all have affected the regional and national economy, causing great social impacts.

The appropriate management of water resources, in view of the climate change, will depend upon the knowledge about its availability and on how this availability will be affected by the different scenarios. Thus, it is necessary to improve the existing studies, reduce the uncertainties and increase the amount of details about the information.

Despite there being several studies on surface water availability, one has noticed that studies on ground water availability are scarce. There is very little experimental evidence on the level of resilience of Brazilian ecosystems, which is crucial to determine the survival of the ecosystems in the scenario of climate changes.

Some adaptations actions of the water resources, to the climate changes could be:

1) Improvement of the infrastructure of the sewage and water supply systems.
2) Reduction of leaks.
3) Implementation and encouragement of conservation measures of water use, by the industries and by the population.
4) A demand for measures that avoid water waste for the approval of new construction projects.
5) Recovery of natural ecosystems in watershed areas.

6) With regards to the risks of floods and landslides, it is necessary to improve identification of the areas of risk.
7) Alert systems of weather forecasts and a preparation for natural disasters.
8) Avoid new ventures in high risk areas and relocation in areas of extreme risks.
9) Improvement or creation or warning systems for floods and landslides.
10) Promotion of design and anti-flood materials for buildings.

Due to its important social function as a source for human supply, it is necessary to improve the assessment of the potential of aquifers in the country and how this potential will be affected in the future. This study will be important to determine how the ground water reserves can contribute towards the mitigation of these changes.

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Chapter 13
Summary

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In an Interview to the Reuter News Agency, Zafar Adel, the current president of UN-Water (where he coordinates the works related to the water of 26 UN agencies) and Director of the Water, Environment and Health Institute of the UN of the University in Canada, said that water impacts every moment of our lives, weather it is on society, weather on natural systems and the habitats. He also said, that the disturbances to the environment can threaten agriculture and the supply of fresh water from Africa to the Middle East, and can generate conflicts because of its scarcity, as already is seen for example in Darfur in Sudan, where it is a factor that contributes towards wars. However, Zafar Adel also mentioned that water has also served, in several instances, to promote cooperation and cited, as an example, that India and Pakistan collaborated towards managing the Indo River, despite their land conflicts, and that Vietnam, Thailand, Laos and Cambodia cooperated in the Commission of the Mekong River.

Zafar Adel mentioned as well, that water deserves a more central placement in debates over food security, peace, climate changes and the recovery of financial crises, for it is crucial in all of these discussions; however it is not usually seen as such. He also highlighted the efforts towards management of water supply, accounting for the amount of water encompassed in products (virtual water) ranging from meat to coffee.

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He concluded his interview stating that the world can meet one of the goals of the millennium—that of reducing by half, by the year of 2015, the portion of people who do not have access to fresh water, but that it is clearly failing at one of its other goals: that of improving sanitation. He exemplified that about 2.8 billion people do not have access to basic sanitation.

The workshop called "The water crisis and national development: a multidisciplinary challenge" held in Belo Horizonte, State of Minas Gerais, on the 29 and 30 of October 2009, had already addressed debates about this, however, focused on our country. The meeting counted with participation of renowned specialists in the areas of management, supply, ground water, climate changes, political geography, limnology, chemistry and engineering. At the plenary session of the workshop, the discussions over the themes presented were consolidated, highlighting some of the aspects considered crucial for the improvement of the management of water resources in Brazil, with special emphasis on suggestions to be included in the National Plan for Water Resources and on consideration which need to pass on to the National Water Agency and to the Ministry of Science and Technology. The following issue deserves special attention: management of transboundary waters, detailing of aquatic eco-regions aiming at conservation and the sustainable use of water resources, training of municipal managers, increase of water reuse, creating geological reference of water with regards to supply, contamination and geodynamic processes, recovery of historical series, effects of climate changes, and water safety scenarios, among others.

The management of water resources in our country has been experiencing a considerable leap in quality in the last 30 years, with focus on an efficient and multi-objective public management. Law number 9433/1997, of Management of Water Resources in Brazil, was the cornerstone of this new phase, as was the creation of the National Water Agency (ANA) in 2006. The shared management of water resources becomes a challenge for society, for the public financial resources become diluted in the face of the increase of population, of the environmental problems and of the global economic crisis. Brazil might benefit, by being a producer of commodities, from its territorial extent and its geographic position in the planet. Then, faced by this dilemma, how will the Brazilian society deal with scarcity of water in the near future? This is the challenge faced by the managers of public policies.

However, alterations in the biological cycle caused by the process of global climate changes tend to aggravate the situation. Almost 90 % of the approximate four billion annual cases of diarrhea in the whole world are attributed to deficiencies in sanitary sewage and in the provision of good quality water for public consumption. In Brazil, the main public health problems associated to water are diarrheic diseases, diseases whose vectors are aquatic (malaria and dengue), schistosomiasis, leptospirosis, several helminths and poisoning by cyanotoxins. One should also consider the increase in conflicts over the use of water, the elevated costs associated to billing for water, the response from the financial market to the companies who promote conservationist practices, and the appeal that the positive environmental image has been causing on the industrial sector, stimulating them to implement extensive programs of environmental management. A significant commitment of industrial and agricultural industries towards goals to reduce water consumption, reuse and recycle industrial effluents has been occurring as a result of such actions. Yet, the universal practice of reuse of water in Brazil in all sectors is today, far from becoming a reality and will only occur through a political institutional decision and through the enactment of a realistic legal framework, which can be effectively implemented through the hydrographic basin committees.

The variety of Brazils within our Brazil, which can clearly be seen through the endless number of landscapes, races, climates and economies, generate a vast disparity with regards to distribution and quantities of water resources in its territory. The edaphoclimatic and social economic characteristic of the so called Brazilian semi-arid requires specific usage technologies for their water resources. In this region, aside from the state of scarcity of water, almost perennial, the incorrect use of water increases the region's fragility to the process of desertification. One should address, in this context, the problems deriving from water scarcity and those relevant to the supply of spread out communities taking into consideration alternative technologies, which are of low cost and accessible to the population. Some of these alternatives and the importance of the integration works between hydrographic basins for this region should be dealt with as an absolute priority, in order to enable a management of its water resources focused on conservation and sustainable use.

The Northeast of Brazil is the most exposed region to the risks of climate variability and to a possible process of aridization and subsequent desertification due to the climate changes themselves. It is estimated that by 2025 more than 70 % of the cities located in the northeastern semi-arid region, which possess a population of more than 5000 inhabitants, will face a severe crisis of water supply for human consumption. As per ANA's estimate, supply problems should affect about 41 million inhabitants of this region. The situation is also worrisome in Amazonia, where the possibility of occurrence of periods of intense droughts can surpass the current 5 % (a severe drought every 20 years) to 50 % in 2030 and 90 % in 2100.

In the densely populated centers, urbanization increases competition over the same natural resources (air, water and land) within a small space for all human needs related to life, production and recreation. The infrastructure for water usually includes, in urban centers, water and sanitation. Sanitation refers exclusively to the collection and treatment of domestic and industrial effluents, never including drainage and solid residues. However, both are components of a sustainable urban environment that includes environmental conservation, health and the social economic aspects of urban development. Urban water management itself is fragmented, indicating that there is no integration between the services of the agencies, nor a company that manages the services as a whole. The results are therefore poor and there is no indication of being efficient. In addition, the increase in population added to the diversification of the multiple uses of water, the constant withdrawal of water for varied purposes and the loss of water retention mechanisms has considerably decreased availability, causing numerous problems of scarcity. In the urban scenario, the above situation is aggravated by the growth of irregular occupation of land and by the complete lack of a sanitation system or, at least, by an efficient system of sanitation.

Brazil has been exploiting, in a growing and worrisome way, ground water to supply cities and urban centers, as well as industries, irrigation and tourism. Despite its evident contribution to the social economic development of many regions of Brazil and its ecological role in maintaining the base flow of bodies of water, the management of ground water is still very incipient and does not reflect its current or strategic importance. The lack of public policies for this sector becomes painfully noticeable when one observes the gap in knowledge about the state of use and the potentiality of aquifers, as well as the risks of anthropogenic contamination to which they are subject to and which affect their quality. The water matrix of our country does not properly contemplate this resource, and therefore loses opportunities to efficiently use water, which would allow us to reduce costs related to the implementation of water supply systems and operational systems, and render the source more protected from events associated to climate changes. We lack, in our country, a disciplining of ground water use, acknowledging the areas of greater demands and assessing the dangers of an over exploitation. We also lack protection of aquifers and their catchments, with regards to anthropogenic contamination. Lastly, we lack the determination of technical information that allow for the use, in an integrated and synergetic way, of surface and ground water resources.

There is a pressing need therefore of promoting a more effective integration of Science, Technology and Innovation with the integrated management of water resources and with the water governance. The State should invest more efficiently in research in the areas of contamination, eutrophication, persistent organic pollutants, monitoring technologies and studies of bioindicators, aiming at promoting a more efficient management of surface and ground water resources at a hydrographic basin level. Investments should also be directed towards the development of technologies for desalination and reuse of water, aiming at reducing demand and at a regional economy of the resource. The implementation of scenarios and ecological and mathematical models will be crucial in the selection of new opportunities and alternatives for management. The economic valuation of the services of ecosystem can add new perspectives to the use of economic tools for the management of water. A more effective interaction among ecologists, limnologists and engineers is absolutely necessary and indispensable for a systemic vision. And lastly, the use of strategic studies will promote new possibilities in the integrated and predictive management at a hydrographic basin level.

The current outlook on water in Brazil seems gloomy. Despite being the owner of an immense contingency of bodies of water, since the country has about 12 % of the world's water resource availability, the distribution of these resources is extremely uneven in the country. To exemplify: 80 % of these reserves are found in Amazonia, while the semi-arid region only has 4 %, even when including the large hydrographic basin of the São Francisco River.

We have to therefore urgently take care of our waters, so that these do not become scarce, or where they exist, prevent them from presenting inadequate characteristics for human consumption. With this in mind, we need to highlight the following:

1) The new challenges for the management of water resources include decentralization of management to regional hydrographic basins; the organization and the support towards basin agencies as executing agencies of the management policies and proposals; and the capacity of innovation and organization of scenarios based on data bases and historical series of each hydrographic basin.

2) There is the need for supporting advanced researches on water resources and aquatic ecosystems; the ecological functioning of rivers, lakes, dams and estuaries should receive greater attention in the form of massive investments in interdisciplinary teams capable of dealing with the challenges and of producing new knowledge with high added value.
3) Advancements in quality and quantity monitoring of surface and ground water is crucial. There is a need for investments in monitoring technologies and in the organization of regional monitoring networks integrated to management technologies. The integration of the monitoring data with the systems of basin management, geo-processing, modules and models of load generation in the basins should improve in an extremely positive way, integrating the water mesh and the quantitative information of the watershed. The creation of interfaces between the data from monitoring, the database systems and the historical series, and the processes and methods of basin management is yet another item of exceptional importance for watersheds.
4) The organization of a network of studies that integrate data on water quality with human health in another urgent need in Brazil. There is limited epidemiological information in Brazil on the impacts of quality water on human health and their short, medium and long term effects. Periurban areas of large metropolis have vulnerable population with an increased risk of water borne diseases, due to the poor quality of supply water, to precarious basic sanitation and due to the poor living conditions.