Water Quality In Brazil

Adalberto Luís Val, Carlos E. de M. Bicudo, Denise de C. Bicudo, Diego Guimarães Florencio Pujoni, Fernando Rosado Spilki, Ina de Souza Nogueira, Ivanildo Hespanhol, José Almir Cirilo, José Galizia Tundisi, Pedro Val, Ricardo Hirata, Sandra Maria Feliciano de Oliveira e Azevedo, Silvio Crestana and Virginia S.T. Ciminelli

1. The Water Quality In Brazil: Historical Perspective

Industrial development, urbanization, and agricultural activities in the last 50 years contributed extensively to the complex and delicate situation of water quality in Brazil. The historical process of water quality degradation somewhat followed the worldwide path described in Tundisi *et al*. (2015) and was clearly described in Bicudo & Bicudo (2017). First, the industrial development produced effluents with heavy metals, dissolved organic substances, and other toxic materials. Accelerated urbanization after the year 1950 together with inadequate wastewater treatment contributed to the accumulation of organic matter and the eutrophication of rivers, reservoirs, and lakes. The extensive agricultural activities, the heavy application of pesticides and herbicides, and the uncontrolled use of fertilizers, especially in regions of widespread sugar cane and soy bean plantation, also contributed to water quality degradation. Today, eutrophication is one of the major environmental problems in Brazil with enormous economic, ecological, and human health consequences.

Mineral exploitation of iron, gold, and other metals is another cause for the degradation of the water quality in several regions of Brazil. Arsenic, mercury, and lead are all typical contaminants that may be related to this activity. Mozetto *et al*. (2003) described how metals and nutrients are weakly bound in sediments of the Tietê River (São Paulo) and what this would cause to human health. In the last few years, floods, large disasters such as the Doce River contamination by a tailing dam failure, and other intense discharge of toxic substances aggravated the picture of the water quality degradation. Deforestation activities all over the country, including removal of riparian vegetation also affect water quality of water bodies and contribute to deterioration. Urban rivers and reservoirs are environments of particularly high impact on water quality due to increasing exploitation.

Adalberto Luís Val dalval.inpa@gmail.com Instituto Nacional de Pesquisas da Amazônia, Manaus, AM, Brasil. **Carlos E. de M. Bicudo** cbicudo@terra.com.br Chapter Coordinator, Instituto de Botânica, São Paulo, SP, Brasil. **Denise de C. Bicudo** denisecbicudo@gmail.com Instituto de Botânica, São Paulo, SP, Brasil. **Diego Guimarães Florencio Pujoni** diegopujoni@gmail.com Universidade Federal de Minas Gerais, MG, Brasil. **Fernando Rosado Spilki** fernandors@feevale.br Universidade Feevale, Novo Hamburgo, RS, Brasil. **Ina de Souza Nogueira** isnogueira.ufg@gmail.com Universidade Federal de Goiás, Goiânia, GO, Brasil. **Ivanildo Hespanhol** ivanhes@usp.br Universidade de São Paulo, São Paulo, SP, Brasil. **José Almir Cirilo** almir.cirilo@gmail.com Universidade de São Paulo, Piracicaba, SP, Brasil. **José Galizia Tundisi** tundisi@iie.com.br Chapter Coordinator, Instituto Internacional de Ecologia, São Carlos, SP, Brasil. **Pedro Val** pedroval07@gmail.com Universidade Federal de Ouro Preto, MG, Brasil. **Ricardo Hirata** rhirata@usp.br Universidade de São Paulo, São Paulo, SP, Brasil. **Sandra Maria Feliciano de Oliveira e Azevedo** sazevedo@biof.ufrj.br Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brasil. **Silvio Crestana** silvio.crestana@embrapa.br Empresa Brasileira de Pesquisa Agropecuária, São Carlos, SP, Brasil. **Virginia S.T. Ciminelli** ciminelli@demet.ufmg.br Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil.

Consequences of this large-scale process are very relevant. First, the economy of municipalities and states are negatively impacted. Second, the impact on human health is also not totally understood yet. Deteriorated water quality results in high costs for water treatment to provide adequate drinking water to the human population. Deterioration of biodiversity is yet another consequence of low water quality and environmental disasters affecting rivers, reservoirs or lakes. Due to this scenario, few watersheds of Brazil can be considered pristine. Therefore, the restoration of water quality in Brazil, the protection of the few pristine watersheds left, and the enforcement of environmental laws are some of the important actions necessary to promote better life quality, reduce risks and vulnerability to water security and promote economic growth. It is fundamental to monitor all regions consistently with the maintenance of permanent and public databases to support public policies.

In this volume, we outline the current state of water quality in all regions of Brazil including some of the main challenges for surface and groundwater. Furthermore, we present some specific challenges, such as the emerging risks of pesticides, herbicides, hormones, and climate change. Lastly, we discuss the economic implications of water quality degradation and make some remarks about the reduction of water vulnerability in Brazil.

2. Water Quality: North Region

In the Amazon everything is great and diverse. The extensive watershed originates in the Peruvian Andes, specifically in the Nevado Mismi, and spreads across all the countries of northern South America, covering an area of seven million square kilometers. The Amazonas River, the main water course, reaches the Atlantic Ocean after flowing for 6,992 km, where it discharges 20% of all the fresh water that reaches all marine environments of the world. This volume of water is five times greater than that of the Congo River (Africa) and 12 times than that of the Mississippi River (United States of America). Each small space is unique in the Amazon. This holds true for water too. It was the German limnologist Harald Sioli who initially described the three basic water types of the Amazon: the white waters of the Solimões/Amazonas river; the black waters of the Negro River; and the clear waters of the Tapajós (Sioli, 1950). These distinctions are not just based on color, but mainly on physicochemical and biological characteristics. The white, or rather muddy, waters of the Solimões-Amazonas River have a near neutral pH, a large amount of suspended sand from the Andes and riverbanks, low concentration of dissolved organic carbon (DOC), and higher nutrients relative to other water bodies of the Amazon. Black water rivers (*i.e.* Negro River) differ in that they show an acid pH ranging from 3.2 to 5, high levels of DOC, and very low levels of sodium, potassium, and calcium. The clear waters (*i.e.* Tapajós River) have a pH between 6 and 7, low levels of DOC, sodium, potassium, calcium, and high transparency (Furch, 1984).

A remarkable feature of the Amazon basin is the seasonal variation of river water levels, appropriately called flood pulses (Junk *et al.*, 1989). In the banks of Manaus, the level of the Negro River can vary more than 15 m between low and high-water seasons. Other environmental parameters also show diurnal, seasonal, and even geographic variation, influenced by the interaction with the various environmental characteristics, such as the dissolved oxygen level. Of course, these different characteristics impose challenges of all orders of aquatic organisms. In the case of fish, for example, a broad set of adaptations at all levels of the biological organization has been developed throughout the evolutionary process, so that they can cope with environments that exhibit significant variation in oxygen availability over short periods of time (Val & Almeida, 1995; Val, 1995; Val *et al.*, 2015). Similarly, fish from the Negro River can maintain ionic homeostasis despite the acidity and ion poor characteristics of their environment (Gonzalez *et al.*, 2002; Wood *et al.*, 2014). Today it is known that DOC has a relevant role in this process (Duarte *et al.*, 2016).

There is still much to be said about the adaptations and abilities of the aquatic biota of the Amazon. However, many aquatic organisms are already facing challenges posed by man-made environmental changes. We highlight here, very briefly, three of these challenges. First, the presence of metals from mining in several bodies of water in the region, which endanger several species of fish that are very sensitive to these metals, such as copper (Crémazy *et al*., 2016; Duarte *et al*., 2009). Second, the effect of climate change on aquatic environments, making them warmer, more acidic and with less dissolved oxygen, conditions that represent an intensification of the challenges that many aquatic organisms of the Amazon already face (Oliveira & Val, 2017). Third, the urban impact on the rivers that cross the cities, when they receive a vast amount of new chemical compounds and debris that represent new challenges for the aquatic biota. In this case, two groups of compounds are worth mentioning: plastics and leachate from landfills. Lastly, while on the one hand a great challenge to expand what we know about the pristine Amazonian aquatic environment is needed, on the other hand there is also a gigantic and urgent need for robust information to reduce the anthropic impacts of all orders on the unique aquatic environments that occur in the Amazon.

3. Water Quality: Northeast Region

In order to contextualize the issue of water quality in the Brazilian Northeast, the distinction between hydrochemical quality and quantity of surface water and groundwater must be highlighted. Considering the surface water issue, Northeastern Brazil contains only 3% of Brazilian water and has only two perennial large rivers, the São Francisco, which concentrates 63% of the Northeast water, and the Parnaíba, with 15%. All other somewhat large rivers are intermittent, *i.e.* they only flow in the rainy season. In the coastal region, perennial rivers of small extension are present and are of great importance to water supply for the population and productive activities, chiefly since the majority of the population and industrial production is concentrated up to 150 km from the coastline. In this range closer to the coastline, the biggest problem for river water quality is pollution from domestic sewage and solid waste, particularly along rivers and canals that flow through cities. Although important sewage treatment programs have been partially implemented in the region, especially in the larger urban centers, the economic crisis that began in 2014 and which still affects public policies in the country has decreased the effort to expand the treatment of domestic sewage. The result is that sewage collection is in most Northeastern cities less than 40% of the volume produced, and effective treatment of sewage in major cities, with few exceptions, is below 30%. The issue of solid waste pollution from rivers and canals that cross the poorest regions of the cities is alarming; the deficiency of waste collection services and the lack of environmental awareness of the riverine population transform these small watercourses into floating solid waste reservoirs. Diffuse industrial pollution is another cause for concern as industrial clusters such as garment production growing in areas close to temporary rivers that receive high net waste from production.

Upstream of urban centers and still considering the wettest regions of the Northeast, water quality is usually satisfactory, although there are problems in some rivers resulting from contamination by agricultural activities (*i.e.* sugarcane). In the region crossed by the São Francisco River, despite a relatively higher level of sewage treatment in the main cities compared to other parts of the Northeast, eventual algae proliferation accidents have occurred, damaging the water supply of the cities. It must be considered in this case the presence of many irrigation systems along the river, whose drainage systems can affect water quality.

Concerning groundwater formations, the water stored in sedimentary aquifers are generally of good quality in all aspects. In coastal sedimentary aquifers there is a risk of salinization in many wells as a consequence of high exploitation or vertical infiltration in poorly sealed wells. On the other hand, water quality is greatly impaired by the high concentration of salts in the so-called fissure aquifers in which water percolates between rock fractures. Alarmingly, these salts dominate more than 80% of the region.

4. Water Quality: Central-West Region

The Central-West region of Brazil contains springs of five hydrographic regions (Amazon, Paraguay, Araguaia-Tocantins, Paraná and São Francisco). Besides supplying the Central-West and all the other regions in Brazil, these hydrographic regions also contribute to Paraguay and Argentina. This is the second least populated region, where pristine waters can be found in different locations such as the Formoso River basin in the state of Mato Grosso do Sul (municipalities of Bonito, Jardim, and Bodoquena) and the Federal District (Águas Emendadas Ecological Station). Also, in different places of the Goiás state (especially in the Chapada dos Veadeiros Park region) and Mato Grosso (Poconé) (Tundisi & Matsumura-Tundisi, 2011; Cunha-Santino & Bianchini Jr., 2008; O'Sullivan & Reynolds, 2004). As in the North region, waters can be classified in some types described below.

Thermal waters occur due to natural geothermal gradients in the Earth's crust (Goiás, 2006). Thermal localities exist in Mato Grosso (Barra do Garça, Rondonópolis, Juscimeira, Primavera do Leste and Santo Antônio do Leverger cities) and Goiás, the latter being the state with the greatest number of hot springs in Brazil. Thermal springs originate through different aquifers (Araxá, Paranoá, Serra Geral, Serra da Mesa, Aquidauana, Cristalino Noroeste and Guarani). There are 19 natural upwelling sources in the state classified as isothermal (36-38°C) and hyperthermal (> 38°C) springs. The largest hot water complex in the country is concentrated in the Caldas Novas and Rio Quente municipalities (Goiás, 2006), but thermal upwellings also exist in Chapada dos Veadeiros Park, Lagoa Santa, and Goiás city. Quente River (Goiás) is the largest hyperthermal river in the country and runs through a Cerrado region.

Acidic or black waters are composed of dissolved acids of plant origin with a brownish color and pH < 6. They are registered in different localities of all Central-West Brazil states. Specifically, the Chapada dos Veadeiros Park presents an extensive area covered by acidic water rivers, among which the Negro River in the state of Mato Grosso do Sul and Suia-mixu River in the state of Mato Grosso. Salt and brackish waters are recorded in the Pantanal (Santos & Sant'Anna, 2010; Barbiero *et al*. 2008), in the northeast region of Goiás (Bambuí aquifer that promotes brackish springs, Goiás, 2006). These waters originate in the soil containing these water bodies. Muddy or brown waters are recorded for most of the rivers that run through latosol regions. In Central-West Brazil, the most common type is the ferruginous latosol (Resck, 1991). Waters flowing in this region contains a great amount of iron. During the rainy period, most of the rivers become muddy due to erosion and deforestation.

The region also has a great groundwater reserve. The Guarani Aquifer expands through south, southeast, and central-west regions and contributes to the water supply of a significant portion of the watersheds in the southern Central-West region. Several springs originate from this groundwater system and are exploited for irrigation and public supply. One can also observe cave lakes that are common at the north of Goiás and south of Mato Grosso do Sul states.

Aquatic environments in Central Brazil are important and attractive for tourism and recreation (water sports, waterfalls, pristine lagoons, rivers with rapids). Unfortunately, they are experiencing serious erosion problems, silting, construction of waterways and hydropower plants, and water pivots as well as water pollution (rural and urban). The most damaging of all has been the advance of agricultural and agribusiness frontiers that began with government projects in the 1970s (Miziara, 2006; Rodrigues & Miziara, 2008) and was intensified in the first decade of the 21st Century, promoting intense deforestation, especially in Goiás and Mato Grosso do Sul states. The lack of sanitation and water treatment also contributed for the serious mischaracterization of the watersheds that changed to meet population growth, agricultural, industrial, and commercial supplies.

Currently, there are about 700 hydropower plant (HPP) reservoirs and/or small HPP that modifies the rivers morphology, the water quality, and/or the type of water. The most modified river is the Tocantins with eight reservoirs of various shapes in its course, the largest one being in the state of Goiás (Serra da Mesa Reservoir). The only river not yet fragmented is the Araguaia due to its origin. This river is the largest in central Brazil (Valente *et al*., 2013) and borders the states Mato Grosso and Goiás. There also is the Mato Grosso's Pantanal, the largest continuous wetland on the planet. Nonetheless, some of the rivers that flow into this ecosystem are under some sort of impact (*i.e.* livestock, deforestation, and gold-mining) that affect their water quality.

Another process of extreme importance is the climate impacts, which have been increasing in the last 10 years. Seasons have changed to the point of producing excessive rains and extreme droughts. These conditions lead to processes of large floods and rivers that once were perennial and now dry up during the drought period. For example, in 2017 only in Goiás, more than 15 rivers had total or partial absence of water in their beds, damaging the aquatic biota and the public supply.

Water is an excellent indicator of environmental quality since it is directly influenced by the water regime to which the ecosystems are subjected. Furthermore, volume and flow are also affected by deforestation which is being intensified by climate change (Coe *et al*., 2011). Currently, the concept for sustainable water use in the Central-West Brazil is still anthropocentric and harmful (*i.e.* numerous reservoirs and licensed grants) (Tundisi, 2002; 2014), thus conceptualizing water sustainability in an environmental sense is necessary. Together with the intensive use of water comes the concept of virtual water (Tundisi, 2014), which is used because of its presence in the final product of the food production process, which is ultimately exported to other regions of the country and to the world. This concept is well applied in a region whose economy is based on agriculture and livestock production, and water is therefore fundamental for its economic development. Investigation of water quality in Brazil abides by specific legislation by the National Environmental Council (CONAMA, 357; Brasil, 2005), by the National Water Resources Policy (Brasil, 1997), and by an integrated water resource management system (ANA, 2005). In the Central-West region, application of these laws is still precarious and raises many conflicts such as the indiscriminate use of water and lobby of the agribusiness companies. The only legislation effectively applied focuses on public supply (Consolidation Ordinance, 5/2017; Brasil, 2017). As highlighted here, there are different types of water in the Central-West region and their multiple uses lead to a complex scenario with strong human interference. It cannot be denied that water supports sustainable development in the Central-West region.

5. Water Quality: Southeast Region

The southeast of Brazil is the most populated and urbanized area of the country with about 120 million people. Water quality is affected mainly by the lack of waste water treatment, the discharge of fertilizers from agriculture and effluents of industrial plants, and the contamination of groundwater.

Although the southeast treats a large volume of sewage it is not sufficient for a complete cleaning up of surface waters. About 40 % of sewage is still discharged without any treatment in continental water bodies such as rivers, reservoirs, coastal lagoons, and coastal regions. As a consequence, blooms of cyanobacteria are frequent in the inland and coastal waters. Eutrophication of reservoirs in São Paulo State, for example is very frequent, even a permanent feature in some cases (Tundisi 2018, in press).

Several diffuse sources of water quality degradation also originate in abandoned solid waste residues. These diffuse impacts affect not only surface waters but also underground waters. Deforestation of vegetation mosaics and riparian forests is another main cause of degradation, increasing discharge of pesticides, herbicides, fertilizers to rivers and reservoirs impairing water quality and increasing the cost of water treatment for potable uses. (Tundisi & Matsumura-Tundisi, 2010; Tundisi *et al*., 2015).

Contamination of groundwater in the southeast is an additional impact on water quality. Part of the southeast region uses water resources from the Guarani Aquifer. These resources are used by several small to midsized towns (50.000 to 200.000 inhabitants) as source of public supply of water.

Protection of water quality in the region would therefore include recovery of vegetation in the watersheds, restoration of riparian forests, treatment of 100% of wastewater, and reduction of the open air solid-waste sites in order to avoid contamination of surface and groundwater. Integrated management of watersheds with a systemic vision, strong environmental education of the population, and capacity building of managers are some of the fundamental steps in the recovery and conservation of water quality. Also, strong conservation measures in existing pristine waters could be an excellent tool to maintain a scientific information basis on the original water quality in the Southeast. Preparation of water quality management for recovery and conservation is also essential to adapt to climatic change (Jorgensen, Tundisi, Matsumura-Tundisi, 2013).

6. Water Quality: South Region

The Southern region of Brazil consists of three states, namely Paraná, Santa Catarina and Rio Grande do Sul. The region is occupied by approximately 28 million inhabitants and the climate is primarily subtropical. Industrial activity occurs in large urban centers of the sector, the most frequent being associated with the metal-mechanic industry, clothing, footwear, and food. The vast plains are occupied by large plantations of soybeans, rice, maize, and cattle ranching, whereas the rural mountainous regions are occupied by small farms involved in dairy, swine, and poultry production chains. Educational and income levels are usually above the Brazilian average, although great disparities exist. Paradoxically, the South is often noted for its high human development indicators but is also facing deeper problems regarding water quality which is being impacted by many different pollution sources. Water resources are impacted by the excessive use of agrochemicals, supplementary nutrients (N and P) applied to crops, and industrial effluents from a variety of sources, including metals and other wastes. In the latter case, there are significant cases of contamination by organic solvents and others from processing industries, such as tanneries and paper mills, many times leading to shortening of water supply. However, the greatest impact on water bodies is related to deficits in environmental sanitation: although almost 90% of the population receives treated water, up to 30% of the total domestic sewage is not treated before being discharged onto rivers and lakes. These statistics are even more serious considering that only the state of Paraná has 70% of the treated sewage in its major cities, while only 10% of the sewage is treated before it is released to the rivers in the states of Santa Catarina and Rio Grande do Sul.

This situation of contamination and losses in water quality is even aggravated by several socio-economic and institutional issues that came along with the economic crisis of the last decades by the state governments within this region. The western areas of Paraná and Santa Catarina states, on the border with Paraguay and Argentina, are impacted by industrial swine manure as well as domestic sewage. The large metropolitan areas of the region, especially Florianópolis and Porto Alegre, are highly impacted by low levels of sewage treatment and a consequent increase in costs related to water treatment and waterborne diseases. In the case of Florianópolis, losses in water quality represent a constant threat to the tourism economic activity; the beaches of the city are often closed due to inadequate disposal of untreated debris leading to risks for recreational use. In the city of Porto Alegre, Lake Guaíba, the main reservoir of drinking water in the city, is impacted annually by large algae blooms, resulting from the disposal of untreated sewage from the city itself and its hydrographic basin, which comprises more 5 million inhabitants along all the rivers draining into the lake. The larger cities in the region, those with more than 200 thousand inhabitants, often report more than 6,000 cases of gastroenteritis per year, this being one aspect of the severe impact of water contamination in public health. The whole picture is further hampered by the industrial contamination already mentioned. The municipalities in the Brazil-Uruguay border (most of them crossed by the Uruguay River) are often impacted by no sewage treatment and lack of funds to increase their sewage treatment infrastructure.

In addition to these water quality problems, there are also periodic droughts, especially in the summer months, which threaten the water security of large areas of Southern Brazil. Inefficient management of multiple uses of water has already generated conflicts, especially between the urban population and the agrarian sector, aggravated at times of scarcity. This is worsened by a problematic management and surveillance system. The structure of environmental monitoring, especially in the state of Rio Grande do Sul is largely depleted. The current inspection bodies do not have the financial resources and sufficient staff to carry out their activities.

7. The Water Quality Of Brazilian Groundwater Resource

Groundwater plays an essential role in public water supply in Brazil. According to the National Water Agency (ANA, 2010), half of the country's municipalities is totally (39%) or partially (13%) supplied by aquifers, with a high predominance in small and medium-sized cities. In private water supply, the importance is even more significant, since it has been used to alleviate the severe problems of lack of water of the public system, which is recurrent in almost every Brazilian city, or even a low-cost water alternative. Unfortunately, there is no estimate on this exploitation and local studies have shown that this value is considerably higher than the perception of society and government. This importance is well exemplified in the Metropolitan Region of São Paulo where public water supply is only 1%, but 12,000 private wells (60% illegal) extracting about 10 m^3 s^{-1}, provide water for 20% of the population. This "hidden statistic" is one of the causes of the government's low attention, including the lack of initiatives to protect the quality of aquifers.

The lithological, tectonic, and climatic characteristics of Brazil create excellent conditions for good groundwater quality and mostly naturally potable. Except for high salinity observed in fractured aquifers of the northeastern semi-arid region, natural geochemical anomalies of toxic substances such as F, Cr, and Ba are very limited in area. However, Fe and Mg have a more extensive occurrence and are generally associated with unconfined sedimentary aquifers. In terms of anthropogenic contaminant sources, the situation is more complex and deserves more attention by the government. Nitrate is the single contaminant with a more significant presence in Brazilian aquifers. In urban areas it is almost ubiquitous. This reflects the lack of sewage networks, which only covers 50% of the urban population in the regions where these systems exist, due to the lack of maintenance or age. The problem is not worse because the contamination has been restricted to the shallower portions of the aquifer (usually down to a depth of some tens of meters), also allowing the use of its water in the deeper parts.

Other contaminants in urban areas are petroleum-derived liquid fuels from leaks and poor operation of service stations. Studies by CETESB (2009) in the state of São Paulo have shown that more than 50% of these installations had leaks reaching the aquifers; however, the plume had limited dimensions and impacts. Chlorinated solvents and heavy metals are products that are quite common in industry and are responsible for the most massive and most complex plumes of aquifer contamination in the country. The high toxicity and large volume of product handled by the industry and even disposed of in open dumps and landfills have made these compounds a new and real concern in urban aquifers, especially when present in free phase (pure product) reaching complex aquifers such as fractured ones (Hirata *et al.*, 2015).

There is no information on the situation of groundwater degradation in urban areas. Although Brazil has been a major agricultural producer, there is a real risk of aquifer degradation involving nitrogen fertilizers and some agrochemicals, mainly herbicides and some insecticides. The lack of monitoring networks in critical areas and the deficiency of systematic studies still compromise the understanding of the real situation on water quality. The scarcity of planning and control of territorial occupation in Brazilian municipalities has also contributed to increase the problem of aquifer degradation.

8. Water Quality And Human Health

Safe and adequate water supply is a key resource for social and economic development validated by many international organizations like the World Health Organization (WHO), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and and the Food and Agriculture Organization of the United Nations (FAO). The United Nations General Assembly and the United Nations Human Rights Council recognized in 2010 the human right for safe water and sanitation with a strong participation of Brazilian government (Heller, 2015). However, the WHO & UNICEF (2017) report recently pointed out that only 71% of the global population (5.2 billion people) is supplied with a safe drinking water service available when needed and free from contamination. Therefore, 29% of the global population (2 billion people) still does not have access to this service. Data showed that only 65% of the population in Latin America uses safe drinking water. Sanitation service data are more critical. Only 39% of the global population (2.9 billion people) uses a safe, managed sanitation service (*i.e.* excreta safely disposed of 'in situ' or treated off-site). For Latin America this percentage drops to 22%, the smallest value among all regions analyzed.

Human health is both directly and indirectly impacted by the water quality. Outbreaks of waterborne diseases (cholera and infections as leptospirosis and viruses) common in urban areas may occur as a result of contaminated or inadequate water supply, sometimes affecting thousands of people and causing many deaths. Outbreaks of vector-borne diseases such as malaria and dengue fever, mosquitoes and intermediate hosts (snails) that harbor the worm that causes schistosomiasis can also occur. Globally, there are nearly 1.7 billion cases of childhood diarrheal disease every year. This disease remains as one of the leading causes of child mortality and morbidity in the world, killing around 525,000 five-year-old and younger per year. However, a significant proportion of the diarrheal disease can be prevented through safe drinking water and adequate sanitation and hygiene (WHO & UNICEF, 2017).

Besides this classical scenario of hazards related with water quality, other impacts on human health through unsafe water use may arise from natural toxic agents (e.g. biological toxins, such as those from cyanobacteria and arsenic) or from anthropogenic sources (pesticides, pharmaceutical compounds or other chemical contaminants). Indirect impact is also related with water availability in food production. For example, agricultural productivity is tied to food security consequences in regions where severe droughts or flooding are frequent.

Considering water availability as the first step to guarantee safe drinking water and sanitation services, knowledge that Brazil has 12% of the world's water availability leads to a false concept of a wealthy water supply for different services as human consumption, agricultural and industrial use, recreation, and energy production. As reported in this document, there are important regional disparities. While the North region reaches 68.5% of national water storage with 6.8% of Brazilian population, water availability for human use in the Northeast region is only 3.3% for 28.9% of the Brazilian population. In the most populated and developed region of Brazil (*i.e.* Southeast), only 6% of Brazil's water availability supplies the highest percentage of Brazilian population (42.7%) (Augusto *et al.*, 2012). On average, 83.3% of Brazilian people is supplied with safe drinking water, but the disparities are great. In the Southeast region, this percentage is 91.24% and in the North region, only 55.38% (SNIS 2016). It is important to point out that 34 million Brazilians still do not have access to drinking water pipelines in their houses. Recent data on sanitation service reinforces this regional discrepancy. On average, 51.92% of the population has access to sanitation facilities connected to a sewer system from which only 44.92% of wastewater is treated. At the North region only 10.45% of wastewater is connected to a sewer net, while this service covers 78.57% in the Southeast region (SNIS, 2016).

The link between poverty and occurrence of waterborne diseases is very notorious. Population that lacks these services is predominantly located in the peripheral areas of urban centers and in areas of informal urbanization, which indicates the need for adopting integrated programs for urban development. This picture is in accordance to some public health data. In 2013, 340 thousand people were hospitalized with gastrointestinal infections. If 100% of the population had access to sewage system there would be a reduction, in absolute terms, of 74.600 hospitalizations, 56% of which would occur in the Northeast region (Instituto Trata Brasil-DATASUS, 2014). Among waterborne diseases, diarrhea is the most frequently registered. Diseases related to faecal-oral transmission as diarrhea, enteric fever and hepatitis A were responsible for 87% of the hospitalizations caused by inadequate sanitation service from 2000 to 2013.

Water resources contamination including drinking water supplies by human excreta remains a major human health concern. In contrast, the importance of toxic natural microorganisms and their toxins as cyanobacteria/cyanotoxins and toxic compounds, such as heavy metals and synthetic organic contaminants, has only emerged in the last half of the XX century. This concern is connected to the recognition of artificial eutrophication as a developing problem since the 1950s. Human-led increased eutrophication in fresh and coastal water has caused enrichment of nutrients and other pollutant. It has become much more widespread in some regions where the advance rates of agriculture, industry, and urbanization has experienced rapid increase, but without being followed by an improvement in wastewater treatment. This artificial eutrophication affects water quality, including higher incidence of microalgae and cyanobacteria blooms, and has negative consequences to the efficiency and cost of water treatment. In Brazil, bloom occurrence is intensified by the fact that most aquatic ecosystems have the necessary characteristics for an intense growth of cyanobacteria throughout the year.

Cyanobacteria cannot be considered pathogenic microorganisms in the classical sense because although several strains of different species can produce bioactive and toxic secondary metabolites for mammalians, a large part of these compounds will only be released into water after the cyanobacterial cell lysis. The quality of water may be more compromised by the presence of dissolved cyanotoxins than by viable forms of cyanobacterial cells, which could potentially be removed during the conventional water treatment. However, this procedure may lead to rupture of the cells of these microorganisms due to the chemicals used during the treatment process. Cyanobacteria are also often associated with the production of compounds that are responsible for taste and odor in drinking water. Although these compounds cannot be considered as toxic as the cyanotoxins, their presence concerns health authorities given that such compounds frequently result in rejection of the potable water by the population, which in turn leads them to seek alternative sources of water supply. Aquatic environments located in areas of strong anthropogenic impact had a high dominance of cyanobacteria and occurrence of blooms. Potentially toxic species of cyanobacteria have been identified in at least 11 out of 26 Brazilian states, the majority of these records coming from multiple use reservoirs (Azevedo, 2005). In some cases, the cyanobacterial bloom can disappear from the reservoir before health authorities consider them a human health risk. This happens because the authorities may be unaware of the potential damages resulting from cyanobacteria blooms and therefore they assume that the conventional water treatment system is capable of removing any potential problem.

Water contamination by heavy metals and synthetic organic compounds as pesticides or pharmaceutical drugs occur due to the inadequate wastewater discharge into aquatic environments. Only recently human exposure to certain heavy metals, such as methyl mercury (MeHg), cadmium (Cd), and lead (Pb) was considered a health risk. Aquatic systems are particularly sensitive to synthetic organic pollutants due to their chemical characteristics, which may favor bioaccumulation along the aquatic food chain. Reservoirs are more susceptible to contamination by metals and other pollutants because of their mobilization from flooded soils. One important potential consequence of damming is the intensification in the production of methyl mercury, associated to the anaerobic degradation of organic matter. In tropical reservoirs, the Hg methylation process is favored by the high water temperature that favors the intensified microbiotic activity and the reducing conditions in the hypolimnium (Confalonieri *et al.*, 2010).

It is also important to consider that water availability in Brazil largely depends on the weather. Climate change studies have already indicated a reduction in the amount of rain in the North and Northeast regions of the country of up to 20% by the end of the XXI Century (Marengo, 2008). Changes in weather and climatic patterns are affecting human health by increasing morbidity, mortality, disabilities, and by the emergence of diseases in previously non-endemic regions. Multiple factors are associated with the region's vulnerability to climate change, water quality and sanitation services. It is well known that water scarcity in the Northeast region affects health of the population, and most of the health problems derive from socio-environmental processes caused by drought. Outbreaks of vector and waterborne diseases can be triggered by extreme events. There is some good epidemiological evidence of human health risk linked to climate variability. Most of that evidence comes from malaria studies. The number of cases of malaria has increased in urban and rural Amazonian area undergoing large environmental changes. El Niño drives malaria outbreaks and linkages between ENSO and malaria is also reported for Amazonia (Oki & Kanae, 2006, Field *et al.*, 2014). The link between malaria and El Niño is due, in part, to the increasing amount of surface water providing breeding sites for mosquitoes. Unlike malaria, dengue fever (DF) is mostly an urban disease whose vector is also affected by climate. In Rio de Janeiro, a 1°C increase in the monthly minimum temperature led to 45% increase of DF in the subsequent month, while a 10-millimeter rise in precipitation led to a 6% increase in DF in the following month (Gomes *et al.*, 2012). Schistosomiasis (SCH) is endemic in rural and peripheral urbanized regions of Brazil. It is highly likely that SCH will increase in a warmer climate. Hantaviruses as well have their prevalence increased due to El Niño and climate change events. Also, incidence of visceral leishmaniosis has increased in Brazil in association to El Niño and deforestation (Field *et al.*, 2014).

The data discussed here shows that the relationship between water and health conditions is usually very complex and mediated by several factors of physical-geographical, socio-environmental, economic, and cultural nature. Indeed, all sectors of the development nexus are interlinked through water. The growth of population and economic activities are linked to water availability and use in agriculture, industry, energy consumption, and domestic purposes. These factors contribute to an increasing demand on the local and regional water supplies. These forces are rapidly accelerating, often with unpredictable changes that represent new uncertainties for water managers, which poses an increasing risk for public health. At the same time, climate change is generating new uncertainties regarding freshwater supplies and to the multiple sectors of water use. As water availability becomes more uncertain, society will become more vulnerable to a wide range of risks associated with inadequate water supply, including hunger and thirst, high rates of disease and death, loss of productivity and economic crises, and degraded ecosystems. Therefore, these challenges require an urgent implementation of policies that will be able to serve as a tool for monitoring the access and use of good-quality and its relations with health indicators.

9. Water Quality And Economic Impact

Identifying and estimating the significance of impact on water quality is of relevance to policy makers seeking to promote sustainable water resources management and wider economic development. A failure to account for externality effects leads to a misallocation of resources to an inappropriate mix of land uses and inappropriate management of individual parcels of land (Moxey, 2012). The economics of clean water is strictly related to its different uses and shall be valued accordingly for: agricultural irrigation, industry, households, water-based recreation (fish, wildlife habitat and navigation), water load dilution, hydroelectric power generation, conservation of biodiversity, and health. In Brazil, a whole set of problems resulting from the intensification of human activities such as urbanization, industrialization, agriculture, and energy production leads to economic impacts of major proportions not yet properly measured but certainly very significant (Tundisi *et al.*, 2015). For example, water treatment for potable water production is extremely expensive. About US$ 60.00 to US$ 90.00 is required for the production of 1,000 m^3 of drinking water from degraded sources. Instead, the cost to treat pristine and uncontaminated waters may reach a maximum of US$ 3.00 (Tundisi & Matsumura-Tundisi, 2010). However, there are other externalities' effects: hospitalizations due to waterborne diseases as well number of hours lost in school due to absence; number of hours of work lost due to illness from contaminated water or intoxication by toxic substances.

Recreation, tourism, public supplies are threatened by eutrophication and silting, which represents the impact of nitrogen and phosphorus on untreated sewage and soil erosion. Between 30 and 40 percent of the world's food comes from the irrigated 16 percent of the total cultivated land; around one-fifth of the total value of fish production comes from freshwater aquaculture; and current global livestock drinking-water requirements are 60 billion liters per day (forecasts estimate an increase of 0.4 billion liters per year). In Brazil, only 5.4 million hectares are under irrigation considering its potential of 29.6 million hectares. Runoff, soil loss, and leaching of chemicals are particularly of great concern considering the tropical climate with its high intensity rainfalls in areas under fragile soils and inadequate management practices.

Regarding chemical contamination of water from non-point pollution sources such as the agriculture ones, the Brazilian market for pesticides is in the world's top level. The industry of pesticides accounted for US$ 9.71 billion dollars, according to 2012 data, referring to 823,226 tons of commercial product and 346,583 tons of active ingredient added to a total of 29.53 million tons of fertilizers. In addition, the impact of climate change, demography, land use and the impact of new and emerging contaminants on surface and groundwater must also be considered. These pollutants are the result of the addition of drugs, cosmetics, antibiotics, hormones, nanomaterials, paints and coatings dissolved in river waters, dams and groundwater and constitute the most recent threat to human health, biodiversity, and ecosystem functioning (Boxall, 2012).

Reliable water resources database to promote recovery and conservation policies (ex. water and nutrients reuse) is a must. Economic assessment of water pollution must be prioritized. Finally, advanced technologies as big data, robotics, internet of things, and 3-D manufacturing is making real the integration of urban, rural, and industrial spaces and societal activities. Predictive models and simulations using big data tools shall be exploited to promote intelligent and long-term water quality management.

10. Water Quality And Surrogate Variables: The Alto Tietê River Basin

Several plans and studies have recently been made to critically evaluate the drinking water supply in Brazil. Among them, there are different security plans for water supply in Brazil and internationally (SUS, 2012; Bensousson *et al*., 2012; PAHO/WHO, 2012; BRAZIL, 2014). Even though these publications outline good proposals, they did not consider fundamental aspects of normalization, criteria for water treatment, and the traditional Brazilian operational procedures adopted by water companies. So, the Ordinance MS-2914/2011 was based on foreign standards or from the WHO Guidelines, without being adapted to social, technical, and public health of Brazilian conditions.

The evolution of guidelines and standards related to public health are not based only on epidemiological and toxicological studies. Technological development, socioeconomic, cultural, and hygiene practices as well as public sensitivity and perception play an imperative role on stablishing guidelines for quality criteria to ensure health protection of consumers (Hespanhol & Prost, 1994). The work done by WHO is divided in two phases. The first phase is the preparation of WHO Guidelines, which are done based on a risk-benefit approach by the Collaborating Centers of WHO (all of them situated in industrialized countries), according to their specialty on one or several variables. These guidelines specify maximum concentrations of various bioactive substances in drinking water by considering a minimum or tolerable reference risk (risk equal to 10^{-6} of developing the disease in 70 years). The second phase, risk management, is to assist developing countries in the preparation of their own national standards and regulations considering their specific environmental, social, economic, and cultural conditions. However, excessively restrict considerations and policies may endanger public health by not allowing their effective application due to economic reasons.

In relation to traditional procedures within water companies, many industrialized countries recycle filtered backwash waters into the water treatment plant with previous treatment to avoid bacteria, protozoa (mainly *Cryptosporidium* sp.), solids and organic matter to return to the plant. In Brazil, on the other hand, filter's backwash waters are recycled to the plant without treatment. This generate a build up of those pollutants in the plant, jeopardizing the production of safe water. This and other practices lead to severe problems in public water supply. For example, during the drought that affected São Paulo in 2015 (Kelman, 2015), water distribution companies adopted the emergency measure of stopping the water distribution to some sectors of the city in a time span ranging from a few hours to a couple of days. When water distribution is interrupted and users continue to draw water from the network it causes negative pressure inside pipes and, due to precarious conditions (e.g. cracks), external matter is sucked inside the tubes. When the water distribution restarts, a huge mass of pollutants is delivered to users. Therefore, intermittent supply operation should be officially forbidden.

The Metropolitan Region of São Paulo (MRSP) comprises the city of São Paulo and 38 adjacent cities. The whole area is 700 m above sea level and most of it is situated in the Alto Tietê river basin (upper Tietê River basin). Currently, the population size is about 21 million people and is estimated to reach 25 million by 2025. Surface water from superficial reservoirs for drinking supply (Cantareira, Guarapiranga, Alto Tietê, etc.) totals 74 $m^3 s^{-1}$. Adding another 10 $m^3 s^{-1}$ of ground water, the overall available water is around 84 $m^3 s^{-1}$. About 80% of this water (67 $m^3 s^{-1}$) becomes raw wastewater. Since the installed capacity of wastewater treatment is only 18 $m^3 s^{-1}$, the difference of 49 $m^3 s^{-1}$ is discharged without any treatment into the waterways (*i.e.* rivers and reservoirs). This critical situation will become worse when the transposition of new waters from other water bodies (*i.e.* São Lourenço River, Paraíba do Sul Reservoir, Billings Reservoir, Taiaçupeba, Itatinga-Jundiaí, Guaió, Juquiá-Santa Rita and Itapanhaú) bring an additional 20 $m^3 s^{-1}$ of water to the MRSP. Considering water losses between 20% to 80% as change from water to wastewater, this operation will generate an extra 13 $m^3 s^{-1}$ of raw wastewater.

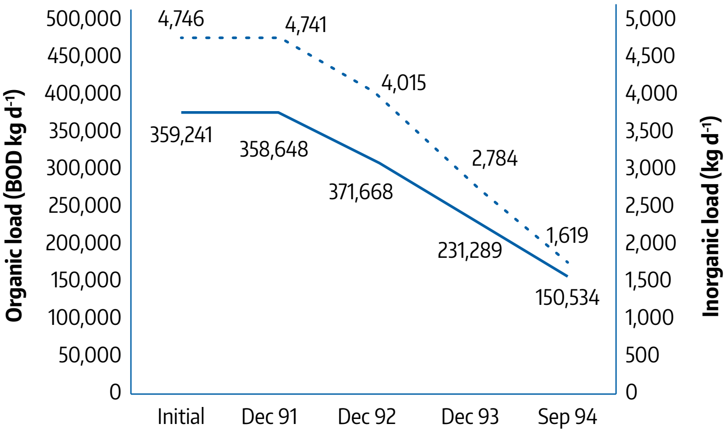
Several attempts were made to control water pollution in this river basin. As early as 1953, a plan involving the construction of six wastewater treatment plants at secondary level was proposed by the city of São Paulo. Since then, many other plans were proposed, however, only in the late 1980s and early 1990s, did the construction of the SANEGRAN Project take place. This project included, among other features, a wastewater plant with a treatment capacity of 63$m^3 s^{-1}$. With exception of the SANEGRAM Project, none of the other projects were accomplished.

In the mid 70's, a state law in São Paulo (State Law nº 997, 1976) required industries to discharge wastewater into the public sewer network whenever possible. The organic load of 370,000 kg BOD d^{-1} at the outlet of the process was reduced to 150,000 kg BOD d^{-1} in September 1994, and the inorganic load from 4,700 to 1,600 kg d^{-1} (**Figure 1**; BOD - Biological Oxygen Demand). This program was abruptly ended by September 1994.

In September 1991, the State Government launched the Tietê Project and the STAR (Sistema de Tratamento de Águas Residuárias or Treatment System for Raw Wastewater) to clean up the rivers and reservoirs of the Metropolitan São Paulo (**Figure 2**).

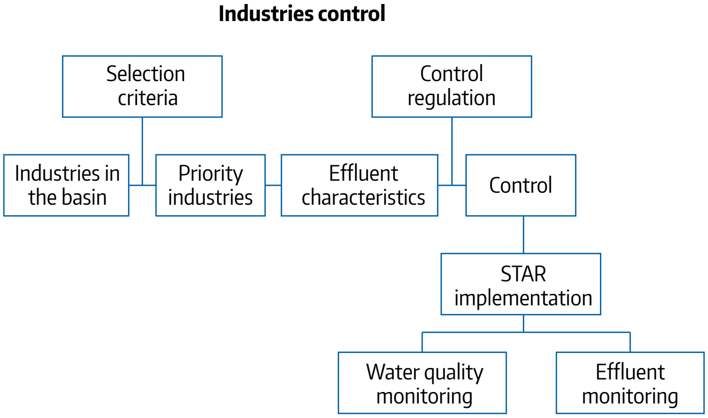
The plans for drinking water are essential for making the direct potable reuse a reality. Direct potable reuse should consider multiple complementary barriers for water treatment, such as ultrafiltration, double pass reverse osmosis, advanced oxidative process, active carbon, and disinfection. This would make it possible to produce high quality water free from organic and inorganic matter, endocrine disruptors, pharmaceutical pollutants, and nanoparticles. The creation of technical groups to study, discuss, and elaborate regulations and standards for water quality is strongly recommended. These studies must be supported by scientists, microbiologists, epidemiologists, toxicologists, biologists, and environmental engineers from Brazil and abroad to produce regulation under Brazilian conditions and not only the biased viewpoint from specialists from water companies and from entities for health and environmental regulation. In addition, if decision makers do not consider the source control, the quality of water produced by conventional systems will degrade even faster. This is why source control must be mandatory in all water quality plans.

Figure 1. Reduction of industrial loads between 1991 and 1994



Source: Herman & Braga, 1997.

Figure 2. Scheme of STAR program



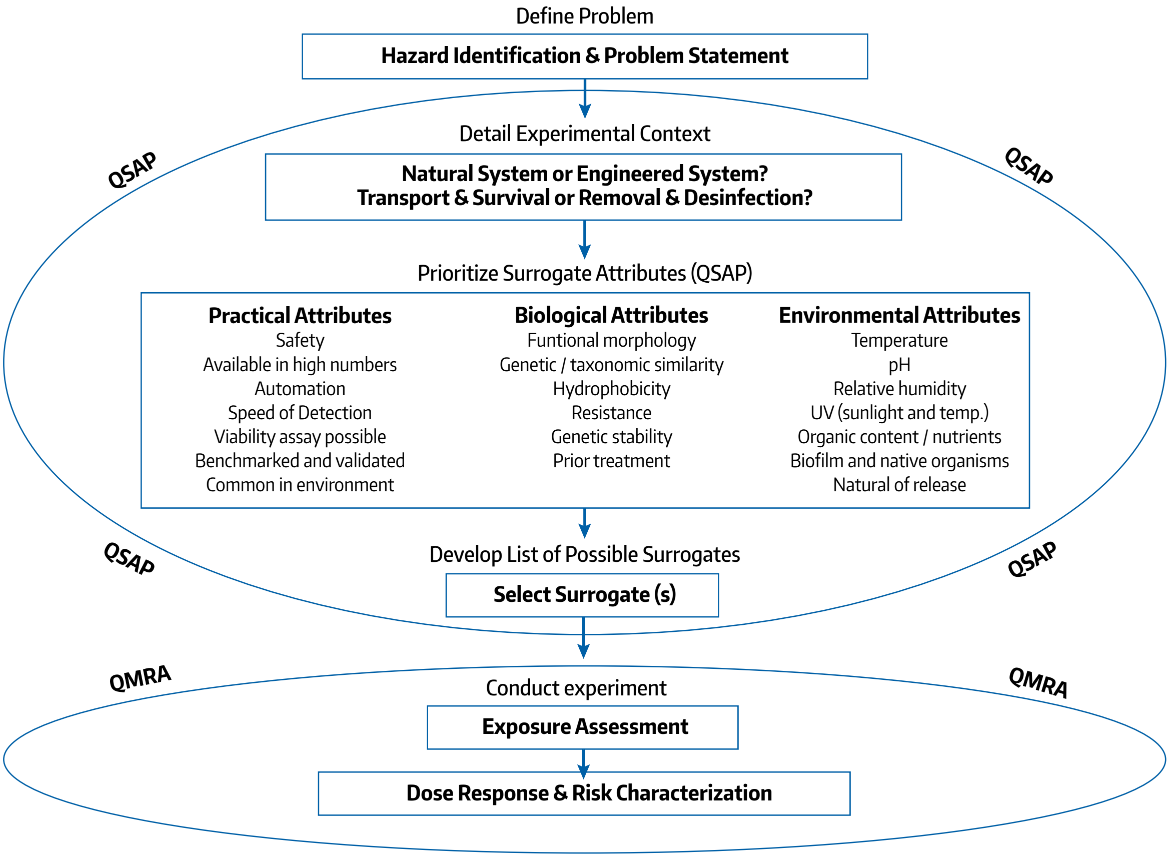
Source: Herman & Braga, 1997.

A new generation for regulations is presented focusing on a new paradigm to reformulate the conventional methodology and criteria to evaluate programs associated with public health, such as drinking water, water reuse, and sludge uses in agriculture. This new generation of standards will make the water security plans more realistic and will reduce monitoring costs. The term surrogate is used to indicate a substitute for a group of variables. Surrogate variables such as microorganisms, particles or substances are used to evaluate the fate of pathogens in the environment. The discovery of the coliform *Escherichia coli* in feces and the methods used for its identification in contaminated waters revolutionized the sanitation field as the *E. coli* could be used as a simple indicator of many waterborne pathogenic organisms. If there is *E.coli* in water, it is likely to have other contaminants as well. Therefore, its use as surrogate variable helps to evaluate the efficiency of water treatment (Sinclair *et al*., 2012). Several surrogate variables are in use today. The most widely known is the Biological Oxygen Demand (BOD), which is used to evaluate the concentration of biodegradable organic matter in water, wastewater and industrial effluents.

Surrogate variables should be evaluated by their correlation with groups of variables represented in terms of Qualitative Surrogate Attribute Prioritization (QSAP), which are to be certificated by Qualitative Microbial Risk Assessment (QMRA). They should be no longer based in proposal of variables by “specialists”. **Figure 3** shows a conceptual scheme for decision-making starting from the definition of the specific theme to be regulated and the elaboration of a list of possible surrogate variables as a function of practical, biologic, and environmental aspects of interest. QMRA selects the most adequate variables, determines the exposure level, the dose-response, and the risk.

Surrogate variables have been used to evaluate the quality of reuse waters for potable uses. In Perth, Australia, the Beenyup Advanced Waste-

Figure 3. Conceptual structure of decisions to select surrogate variables (Sinclair *et al.*, 2012) trihalometanes (Edzwald *et al.*, 1985)



water Treatment was equipped with ultrafiltration membranes, reverse osmosis, and UV radiation disinfection. The effluent is infiltrated through managed aquifer recharge into the sandy aquifer of Leederville, acting as environmental buffer, to produce drinking water (Australian Water Corporation, Project Water Forever-Whatever The Weather, Beenyup Advanced Wastewater Reclamation Plant, Perth, Australia, 2013).

This discussion is relevant to introduce some basic aspects about regulations in Brazil, focusing on the Alto Tietê River Basin in São Paulo. A deep evaluation on how the command and control mechanics work in São Paulo led this discussion to question whether the parameters adopted to control water quality are coherent to the current reality or not. This evaluation focused on how the Environmental Sanitation Technology Company of the state (CETESB) monitors the industrial effluent discharges. In practical terms, it is notorious that the standards adopted as reference in São Paulo, as well as in the rest of the country, are copied from WHO guidelines and USEPA guidelines (whichever is the most restrictive, sometimes rounding some numbers). This premise goes, unfortunately, against what WHO advocates about adapting their guidelines to local standards for risk evaluation related to water consumption. Hence, using pre-established international values without further evaluation may jeopardize the main purpose of the risk analysis, which is to guarantee the safety of the consumers. The main questions that come up in the current scenario are: (1) are there compounds in Brazil that offer a risk to human health but are not considered by either WHO or USEPA? and (2) are people in Brazil investing precious resources to monitor compounds that may not even be present in local waters?

11. Emerging Risks For Water Quality: Climate Change

Over the last 50 years, nutrient enrichment (particularly nitrogen and phosphorus) due to human activities promoted accelerated eutrophication rates. Urban, industrial, and agricultural developments are the main causes of this process. In freshwater ecosystems, phosphorus availability has been viewed as a key factor to limit algal growth. Proliferation of cyanobacteria is thus prevented by the lack of phosphorus in the freshwater ecosystems (Schindler *et al*., 2008). However, the increase in nitrogen load at higher rates than phosphorus can also stimulate eutrophication of estuarine, coastal, and freshwater ecosystems around the world (Paerl & Dawnl, 2012). Besides eutrophication due to excess of phosphorus and nitrogen, another process is effectively acting as a stimulator of cyanobacterial growth and water quality deterioration: the climatic changes in the hydrological system affecting the physical and chemical environment, metabolism, growth rates, and bloom formation (Paerl *et al*., 2011).

An increase of 2°C of the surface water temperature can affect the growth rate of all phytoplankton species and promote rapid increase in cyanobacterial growth rates, causing bloom formation (Paerl & Huismain, 2008). Large masses of cyanobacteria will considerably change the water quality due to the production of antioxidant enzymes and other excreta. This deteriorates the water quality in water bodies and has negative consequences to society as described earlier in this document.

Toxic substances produced by some cyanobacteria species can also be added to the dissolved organic matter content of the water and interfere with pH and the physic-chemical equilibrium. This can also lead to mass killing of fish and aquatic birds and consequently impact human health. Evidences of the impacts of climatic changes and its effects on the hydrological and water quality conditions in lakes and reservoirs are accumulating during the last 20 years. For example, a survey of 143 lakes along a latitudinal gradient from Northern Europe to Southern South America revealed an increase in cyanobacteria-driven phytoplankton biomass that was directly related to temperature (Kosten *et al*., 2011). As for the geographic distribution, *Cylindrospermopsis raciborskii* has a strong capacity of adaptation, prefers water temperatures above 20°C, and is adapted to low light conditions. Today, it is widespread in all continents. In Brazil, Tundisi *et al*. (2005) reported an effect of global change detected at Lobo-Broa reservoir, in São Paulo State. Changes in the hydrological cycle due to climate change, causing extreme events such as longer drought periods followed by heavy rains also has an impact on phytoplankton growth. This relation is described in more detail latter in this text (16. Case Study: Broa Reservoir).

12. Emerging Risks For Water Quality: Agriculture (Pesticides, Herbicides, Hormones)

In recent years, there has been increasing concern over the environmental risks of the Emerging Contaminants (EC). ECs originate from a variety of product types including human pharmaceuticals, veterinary medicines, nanomaterials, personal care products, paints, and coatings. Some ECs are not necessarily new chemicals; they may be pre-existing substances in the environment, but whose presence and significance are only now being recognized. Some examples are natural and transformation products of synthetic chemicals formed in the environment by biochemical processes in animals, plants, and microbes. Data on ECs are often scarce and methods for detection in the natural environment may be non-existent or in its infancy.

Evaluating the environmental fate and effects of ECs includes research on compounds such as surfactants, antibiotics and other pharmaceuticals, steroid hormones and other endocrine-disrupting compounds (EDCs), fire retardants, sunscreens, disinfection byproducts, new pesticides and its metabolites, and naturally-occurring algal toxins. Detection of these contaminants in environmental matrices (water, wastewater, soils and sediments) is particularly challenging because of the low detection limits required, the complex nature of the samples, and difficulty in separating these compounds from interferences. New extraction and cleanup techniques coupled with improvements in instrumental technologies to provide the needed sensitivity and specificity for accurate measurements are very promising.

Relevant contaminants are ECs (particularly hormones and anabolic steroids), antibiotics and other pharmaceuticals associated with wastewater, and antibiotic resistance genes in bacteria and prions (Snow *et al.*, 2009; 2017). In Latin America and tropical countries, very few studies exist and none of those is specifically targeted to agricultural environments (Sodré *et al.*, 2010; Campanha *et al.*, 2015; Machado *et al.*, 2016). The related studies in agricultural systems have detected a range of ECs generally reporting very low concentrations (*i.e.* in the ng L^{-1} range) (Boxall, 2012). ECs of different classes were detected in waters, such as triclosan, caffeine, atrazine, paracetamol, atenolol, estrone, 17-β-estradiol, stigmasterol, cholesterol, and bisphenol. The impacts of ECs in and from agricultural systems will be increasingly relevant in the near future under the scenario of land use, demographic growth, climate change, global increase of food, fiber and energy demands and its impact on agricultural supply. In addition, intensification of agriculture practices is expected for the next decades. Natural resources such as land, water, air, and biodiversity will be highly scarce and the spatial border separating urban from rural areas will disappear. Finally, policy-makers and scientists will have to cooperate to create an initial environmental ECs priority list, to address the consumer demands for safety and the lack of conceptual models for ECs in the environment. Environmental risk assessment schemes already exist in certain regions, however research and policy strategies for ECs and agriculture in the tropics are urgently needed.

13. Reducing Vulnerability: Urban Areas

Today, cities are the engine of the economic development of several developed and developing countries. More than 50% of the world human population is urban. In Latin America, 82% of the human population is living in large metropolis, medium sized, or small cities. Therefore, water quality in urban regions is fundamental for sustainability. Vulnerability in cities is related to lack of sanitation especially in periurban regions and low percentage of wastewater treatment (in Latin America approximately 20% of wastewater is treated). Another vulnerable region of the urban ecosystem is the deforestation of uptown watersheds that supply water for the city. Deforestation leads to losses in the quantity of water due to lack of replenishment of surface and ground supplies. At the same time, deforested areas also reduce water quality and more chemical treatment is needed to produce potable water. (Tundisi *et al.*, 2010).

Integrated water resources management accounting for water quality and quantity in surface and underground sources are fundamental to reduce the vulnerability of cities to water security. The protection of riparian vegetation and the vegetation at the sources of supply is an important measure and promotes water replenishment and actively produces better water quality (Tundisi *et al*., 2015). Wastewater treatment and water reuse are other important measures of management with economic and human health impacts. Water reuse is a low-cost opportunity to increase the current supply of water (Nasiri *et al*., 2013). Monitoring water sources around towns and in urban rivers is another consistent sustainability measure. With such monitoring the information flows and people's involvement can be optimized and stimulate communication in water science and water planning.

The implementation of urban forest parks could increase the sustainability and promote the creation of green areas in cities while creating new opportunities for education, research, water supply, atmosphere, and clean air. Equally important is the protection of natural wetlands at the watersheds of the urban areas. Introduction of new and advanced legislation at the municipalities could considerably advance the reduction of urban vulnerability as well as 1) stimulate programs of re-vegetation of urban areas; 2) decentralize wastewater treatment systems; 3) use rain water in new buildings and houses; 4) introduce new environmental courses at schools. Reducing vulnerability to water security at urban ecosystems implies in biogeophysic, economic, and social measures with a strong scientific and technological background and a robust participation of the people.

14. Reducing Vulnerability: The Mineral Sector

Water has been recognized as a strategic issue for the mining sector as most processes need considerable amounts of water to operate. The participation of the mineral sector in the overall water consumption is small (< 10%) compared to the agribusiness (> 70%) (ANA, 2017). However, the local interferences on water resources cannot be neglected, especially in light of the events of water scarcity in places where water resources have been traditionally considered abundant. Water has also emerged as one of the most significant causes of social and economic tension between industry and local communities, who in turn are often concerned with the risks of depletion and deterioration of surface and groundwater resources. These conflicts directly influence how society perceives mining operations and in turn, the sector's ability to achieve the social license to operate. There are, in summary, several reasons for decreasing vulnerabilities by improving water management: (1) increase access to water resources; (2) reduce management risks (e.g., by reducing water consumption and creating self-sufficient water use, with decreasing need of new resources); (3) decrease competition with other users, especially during events of scarcity and other extreme conditions; (4) saving drinking water for the preservation of life; and (5) build a positive relationship with stakeholders to ensure the license to operate, among other factors.

As a result, increasing the efficiency of water use has been perhaps the main driving force for the recent advances we have witnessed in the mineral sector. The increase in water recycling and use of saline, brackish, sewage and rain water, thus decreasing the use of noble water; the minimization of leakages and losses in industrial operations are some improvements that deserve to be highlighted. The increasing participation of the mineral sector in finding solutions for water scarcity in nearby urban areas is worth mentioning as well (Ciminelli *et al*., 2015). There are various industrial experiences showing that increasing efficiency in the use of water results in the reduction of costs and generation of new revenues. This creates a virtuous cycle and stimulates new and ambitious investments.

What are the main challenges? The first one is perhaps the fact that the sector is quite heterogeneous and therefore good practices should be disseminated among all. Another topic to be addressed is the increasing number of artisanal mining or *garimpo*, often illegal, in many regions in Latin America. This creates uncontrolled impacts on water resources and great vulnerability in the mined territories. The impacts of artisanal mining are not caused by the lack of technology. It is rather a social and economic issue related to the lack of education and infrastructure, poverty and inequality, prevalence of economic interests, and the failure of the state to implement public policies and law enforcement. The 2015 failure of a tailings dam in Brazil added pressure on water/tailings management, and more emphasis on less-dependent water operations, such as dry processing and dry tailing disposal.

Finally, it is clear that water security is essential for the mineral industry to remain competitive and cannot be achieved without a commitment of all stakeholders. Cooperation between different production chains, between industry, society, and governmental agencies is required. An integrated, systemic, and multidisciplinary approach to assess water quality and availability should rely on a sound, well-designed, and reliable database (e.g. real-time metrics). Sharing experiences, knowledge, competencies, information, and responsibility should be expected in the future. This approach is increasingly needed to guarantee a good quality of life and the sustainability of shared territories.

15. Reducing Vulnerability: Biodiversity

Brazil is well known to be one of the richest countries in the world in terms of biodiversity. We are very proud to know Brazil as a megadiverse country. However, what is effectively known about this megadiversity? Since 2009, Brazil is showing some concern about the preservation of its biodiversity, mainly the aquatic one. Also in 2009, a research project carried out by the Brazilian Institute of Geography and Statistics (IBGE) warned the risk of extinction of at least 238 species, which created some concern of governmental, non-governmental, and private institutions. This concern was also demonstrated by the Federal Ministry of Environment that admitted, at the time, that failed the country's attempt to improve the fishing resources management to significantly benefit the sustainable process and, consequently, the aquatic biodiversity scenario in the country.

In 2018, still very little was done to improve this scenario such that Brazil may start a cycle of great progress in fishing activities without being properly prepared. However, biodiversity is not restricted to fish and other marine products, but it is a very broad term that considers, in the case of aquatic biodiversity, both the set of the continental, coastal and marine aquatic ecosystems and the organisms living or spending part of their biological cycle in such environments. Compared to knowledge about diversity loss in the oceans, mainly of fish species of economic interest, little or almost nothing is known about other marine animals, and much less indeed about freshwater species.

Only very recently did Brazil wake up to the biodiversity crisis. Perhaps, the only attempt to measure biodiversity loss in light of the continuous aggravation of the eutrophication problem is the Garças time-series. This record includes 21 years of uninterrupted monthly phytoplankton sampling and simultaneous evaluation of environment characteristics of the Garças reservoir, a system located at the Parque Estadual das Fontes do Ipiranga located in the southern part of the São Paulo municipality. Furthermore, it revealed that of the 36 species of Cyanobacteria known to occur in the reservoir in 1997, only four remained after an abrupt loss between December 2003 and October 2008, which resulted in loss of species richness and diversity. Among those remaining, *Planktothrix agardhii* formed 97-98% of the total biomass in November-December 2005. *Microcystis aeruginosa, Microcystis panniformis* and *Cylindrospermopsis raciborskii* were the other species, all of them Cyanobacteria that resisted the reservoir's rising eutrophication.

Some measures are broadly used in various parts of the world in an attempt to mitigate eutrophication and loss of biodiversity. Among them are: better management practices with optimization in the use of fertilizers, reduction of intensive livestock, improvement of sewage treatment, restoration of lost wetlands in order to increase P and N retention capacity (mitigation of nutrient diffuse loads), reestablishment of buffer zones along rivers (riparian forests) and the water restriction by humans (intensive agriculture retreating in more vulnerable areas, improvement of the water recycling in hydrographic basins, improvement of efficiency of water allocation for their distinct uses and more consistent drought control)

The challenges to be faced in Brazil will demand a lot more effort than that taken in Europe. The Brazilian situation is aggravated by the lack of a consolidated scientific base for the country and the warmer climate, a fact that may lead to ineffective management strategies of the aquatic ecosystems. It is absolutely urgent, therefore, to establish extensive multidisciplinary research programs that will pursue, as far as possible, syntheses, inferences, and the production of information based on the monitoring of time-series, as well as the definition of possible scientific gaps regarding the Brazilian biodiversity.

16. Case Study: Broa Reservoir

The Carlos Botelho Hydroelectric Power Plant-UHE (Lobo/Broa reservoir) was selected in 1971 for a program of ecological research. In the last 47 years, continuous sampling and studies allowed a thorough characterization of this artificial ecosystem and its watershed (Tundisi & Matsumura Tundisi, 2013). The functioning mechanisms of the reservoir were well studied which allowed for measures to maintain good quality of water (*i.e.* low conductivity – average 10-20μScm^{-1}) by means of periodic turbulence with re-oxygenation of the whole water column, high saturation of oxygen (80-100%), low retention time (< 20 days), and an extensive macrophyte growth in the headwaters, ultimately preventing high nutrient load and eutrophication. The phytoplankton composition was consistent with the oligomesotrophic characteristic of the reservoir: predominance of diatoms and chlorophyceae with a maximum of 10μg/l chlorophyll. However, in the winter of July 2014 the following changes were observed: a heavy bloom of cyanobacteria occurred for the first time in the reservoir. This cyanobacteria (*Cylindrospermopsis raciborskii*) is an invasive species. Very high chlorophyll levels (up to 100μg/l) were measured and high concentration and input of phosphorus was also detected. The explanation for this sudden appearance of blooms can be attributed to the following factors: 1) increase of up to 2°C above the average water temperature during the winter; 2) lower rainfall during summer (30% less of the yearly average of 1.500 mm) and increase in the retention time (from <20 days up to 60 days) in order to maintain volumes for hydroelectricity production (Tundisi & Matsumura-Tundisi, 2018). Effects on the overall economy of the region and on the ecosystem services were already quantified (Periotto & Tundisi, 2013).

As described by Paerl & Huisman (2008), global warming affects patterns of precipitation and drought. The changes in the hydrological cycle enhanced cyanobacterial dominance. Heavy rains after extensive drought periods increased nutrient input promoting phytoplankton growth. During periods of drought, residence time increases and promotes blooms. Another consequence of this process is the prevention of silica discharge into the reservoir reducing diatom growth due to extensive periods of drought. The Lobo/Broa reservoir had a predominance of *Aulacoseira italica* during many years due to silica concentrations of up to 5mg/l. This effect of silica reduction was described by Schindler (2006) in a review of eutrophication. As a result, the Lobo/Broa reservoir is currently eutrophic. To our understanding this is a clear evidence of an effect of global changes at a local and regional freshwater ecosystem.

The concepts and the scientific information produced in last 47 years form the basis of the environmental planning. The selection of criteria was based on general mechanisms of functioning and the hierarchical structure of the sub-systems. These criteria were chosen on the following principles:

i. The maintenance of basic processes in the watershed such as the input of allochthonous material of organic origin in the rivers, and the low residence time in the reservoir.
ii. The maintenance of spatial heterogeneity based on the diversity presented by the gallery forests along the streams, and the compartments with macrophytes in the upper reservoir.
iii. The maintenance of adequate water quality in surface water (rivers, small shallow wetlands, reservoir) and groundwater.
iv. The regulation by law and projects of environmental education on the use of (1) the reservoir and (2) the watershed for recreation or other activities.
v. The stopping of all activities known to cause severe damage to the regional ecosystems, such as mining operations; removal of vegetation; introduction of exotic fish species in the reservoir (introduced at first in the decade of 1960); overfishing, and activities that could disturb wildlife in general.

This planning produced a comprehensive synthesis of activities based on the following systems and compartments:

i. The watershed
ii. The reservoir itself and its interaction with the watershed
iii. The small rivers and streams, and the pattern of drainage
iv. The vegetation and the gallery forests
v. The macrophyte vegetation in the small rivers
vi. The soil conservation
vii. The water quality; its conservation; sanitary problems

Considering the wider context, the environmental planning of the watershed consisted in permanent assistance of small communities in monitoring the quality of water supply (surface or groundwater) and in techniques of studying regional ecosystems. Recreation, small scale agriculture, and fishing, are the main activities in progress in the watershed and the reservoir. The guidelines for these actions as well as the programs of environmental education introduced a permanent system of monitoring aiming to reestablish the lost environmental services.

17. Case Study: Guarapiranga Reservoir

Guarapiranga is an emblematic reservoir in Brazil and represents a challenging scenario between good water quality and urbanization. Construction of this reservoir for the generation of electric power for the city of São Paulo started in 1906 and finished two years later. Due to the rapid growth of the Metropolitan Region of São Paulo (MRSP) with a population reaching about 800,000 inhabitants, Guarapiranga became one of the most important water public supply systems in 1929, besides being responsible for other environmental services to the region. Until the mid-60s, changes in the soil use and occupation did not affect the rural scenario that dominated the reservoir margins. Despite the population and urban growth having changed their pace between 1940 and 1960, it was largely after the 70s that an augmented urban occupation developed and accumulated high densities of piled-up allotments and slum nuclei all in parallel to the absence of adequate environmental occupation sanitation infrastructure. Therefore, from the 70s on, this formerly isolated reservoir started to be a part of its urban mesh.

Historical recovery of the environmental changes was obtained from "clues" provided by distinct environmental markers recorded in the sedimentary cores that included 100 years of reservoir history. The eutrophic state dated since 1960 and was strongly associated with the input of domestic effluents and the growth of the land use and occupation impact. Eutrophication triggered the occurrence and increase of potentially toxic Cyanobacteria blooms in the reservoir. Such organisms merit some great preoccupation since they are the cause of several economic, environmental, and health problems as described earlier in this volume. Historically, at the beginning of the 80s, Cyanobacteria blooms started to be much more frequent, impairing the treatment process of the water intended for public supply. Throughout years 1990 and 1991 a phase of severe eutrophication in the reservoir accompanied the first reports of gastrointestinal disorder cases due to Cyanobacteria (*Dolichospermum solitarium*) that affected the population that relied on the reservoir water. Contamination markers related to inorganic micropollutants concentration (e.g. APH, aromatic polycyclic hydrocarbons) were also detected in the reservoir. Decrease in the C:N ratio from upstream to downstream in the reservoir and the consequent increase in the total nitrogen, $\delta^{15}N$ values suggested an increase in the sewage discharge at the final portion of the reservoir. High coprostanol (fecal sterol) values confirmed the sewage presence in 70% of the sampling stations used for the reservoir water ecological quality evaluation. In the upstream area of the reservoir, superficial layers presented lower fecal influence and a mixture of C and N sources ranging between algae and macrophytes. These sources were represented by intermediate values of C:N ratio and $\delta^{13}C$ and by the dominance of campesterol, an algal sterol.

Inefficiency of collection and treatment system for domestic effluents showed that the reservoir has been punctually but intensively receiving high organic loads from its contributing watersheds during the last three decades. Added to the scenario of a decrease of water availability between the years 2013 and 2015, the Guarapiranga reservoir is close to overcoming its depuration power. Thus, the reservoir will transition from an eutrophication and intense sewage influence to a fecal contamination situation in which its ecological functions will collapse. Very detailed information about the reservoir can be obtained in Bicudo & Bicudo (2017). The Guarapiranga reservoir is a legacy of challenges and lessons to be strongly considered during the preservation and recovery of all reservoirs threatened with urbanization.

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