WATER QUALITY IN THE AMERICAS

A SURVEY

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DEDICATION

DAVID WILLIAM SCHINDLER
(1940 – 2021)

Professor David Schindler, Killam Memorial Chair and Professor of Ecology at the University of Alberta (Canada) passed away as this volume was nearing completion. Professor Schindler was a giant in the field of water science and especially water quality. His contributions to the study of the role of phosphorous in eutrophication, the impacts of acid rain on aquatic habitats and the environmental impacts of the Alberta Tar sands -to name but a few- stand as unparalleled examples of how science can contribute to our understanding of the world around us and our impact on it. (Not coincidentally, Professor Schindler was the author of the chapter on water quality in Canada that appears in the larger volume from which the present volume was extracted). These scientific accomplishments were remarkable enough, but his legacy included far more than that. Professor Schindler was an effective and unrelenting advocate for the use of science in the making of public environmental policy. There are more examples than can be counted where he argued with regulatory authorities and others that they were on the wrong track and pointed out how science could be used to correct the errors that they were about to make or had already made. There are few, if any, academics who have made such important contributions to both science and the making of policy. With this dedication, the members of the IANAS Water Committee express their gratitude and admiration for Professor Schindler's scientific achievements, his impact on public policy and for showing us how both should be done.

CHAPTER I
INTRODUCTION

This volume is an abridgement of a substantial work on water quality in the Americas produced by the Water Program of the InterAmerican Network of Academies of Science (IANAS). This work, which is entitled *Water Quality in the Americas: Risks and Opportunities*, was co-authored by some 148 scholars and experts including the members of the IANAS Water Program and their associates. The purpose of the present volume is to provide an accessible overview and summary of the larger document which totals over 600 pages. Unlike the larger version which provides descriptions and analyses of water quality problems on a country-by-country basis and several special chapters, this volume focuses water quality problems on a broader hemispheric basis. While examples are drawn from individual countries, the intent is to provide the reader with an overarching assessment of the water quality problems of the Americas and some of the means for addressing them.

In the 19th and early 20th centuries concerns about water resources were focused mainly on the adequacy of supplies to support domestic, industrial, and agricultural activities. With the advent of the modern era, it began to become obvious that protection and maintenance of water quality is an essential part of maintaining supplies for different uses of water. Continuing declines in water quality frequently result in loss of available supplies as surely as drought. The restoration and protection of water quality is complex and entails a variety of efforts ranging from the management of watersheds to the enactment and execution of water laws and policies. This is especially true today as new and previously unknown contaminants emerge, often before their impacts on water and its uses can be adequately evaluated. Moreover, it is now understood the protection of ecosystems and the production of environmental services require careful management of water quality. Comprehensive monitoring of water quality is inadequate in most of the Americas. Without monitoring it is difficult to assess the scale and extent of a water pollution problem and similarly difficult to know whether efforts to improve and protect water quality have been successful. Monitoring nominally requires public investment and yet the importance of it is obscure to members of the public and efforts to raise public revenues to support it are rarely successful.

The variety of landscapes and climates found in the Americas is bewildering. Yet, there is hardly a country or a region that is not beset by significant water quality problems. Many of those problems have common causes and common management prescriptions. These are set forth in the chapters that follow. In chapter 2, some applications of basic science that are pertinent to the management of water quality are set forth. They lead to some straightforward lessons on what to include and what to avoid in establishing water quality plans and policy. This chapter also contains discussion of two overarching topics that are pertinent to all countries and regions-health and climate change. Chapter 3 contains a survey of the water quality problems found throughout the Americas. These problems include eutrophication, chemical contamination and biological and other non-chemical contaminants. This chapter also includes a discussion of ground water which is becoming of increasing importance as a source of supply throughout the Americas. The protection of ground water quality poses especially difficult management problems which will have to be addressed if this water source is to remain viable in many areas. Chapter 4 contains a brief discussion of water quality governance, institutions and needed policies. There are few places in the Americas that have fully addressed these problems. Chapter 5 contains the main conclusions of this abridged volume.

For those wishing further detail and analyses on a country by country basis or special chapters, the larger volume can be found on-line in both English at:
https://ianas.org/wp-content/uploads/2020/07/02-Water-quality-INGLES.pdf
and Spanish:
https://ianas.org/wp-content/uploads/2020/09/03-Water-quality-ESPA%C3%91OL.pdf.

CHAPTER II

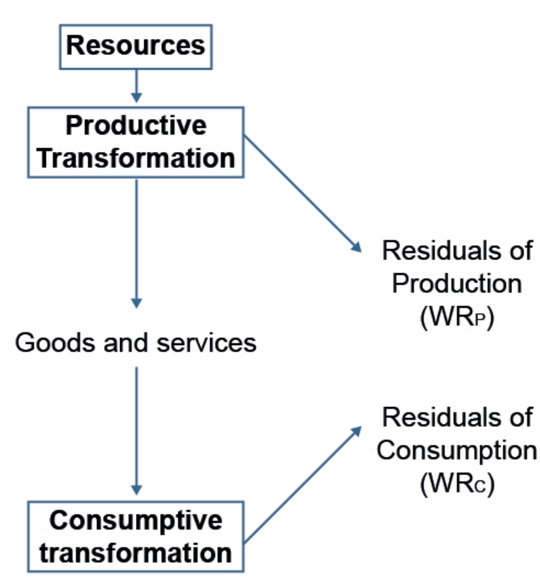
BASIC SCIENCE OF POLLUTION

The term "water quality" encompasses a host of phenomena and, of necessity; the study of water quality must be approached from a number of different disciplines including biology, chemistry, physics, hydrology, medicine and the social sciences. There are nevertheless principles, health effects and the impacts of climate change that overarch the water quality topic. These topics, principles, health effects and climatologic impacts are considered in this chapter.

SCIENTIFIC PRINICIPLES.

Effective management of water quality requir an understanding of the fundamental Law (Conservation of Energy and Matter. This la yields several critical conditions that should n be neglected in devising management strategi and protection schemes for water quality. Th fundamental Law holds that matter and energ are always conserved. This principle requir that resources and material that flow throug production and consumption systems are alwa conserved. **Figure 1** illustrates how this occur On the left of the diagram are the raw materia and resources that flow through the producti processes. The productive processes transfor the materials and resources into 1) useful goo and services and 2) the residuals of the productio processes, WR_P. As a rule, residuals do not hav any value that can be captured and, where they a left unregulated, are discharged into environmental sinks that include land, air and water. The goods and services that are produced are purchased by consumers. Another transformation takes place in the process of consumption in which the residuals of consumption, usually trash and garbage, WR_C, are discharged to the environment. In this analysis it is assumed that residuals are unregulated.

Figure 1. Schematic of the Principle of Material Balance



The Principle of Materials Balance which follows from this analysis holds that the weight of the resources that enter the production process is approximately equal to the weight of the residuals of production, WR_P plus the weight of the residuals of consumption, WR_C. (Ayers, Kneese and d'Arge, 2015).

1) $W_{res} = WR_P + WR_C$

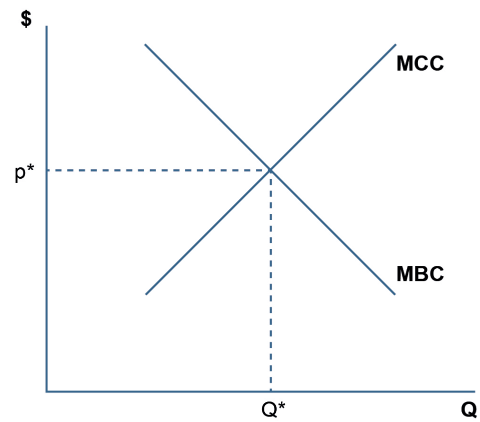
Where

W_{res} = the weight of resources and materials that enter the production processes
WR_R = the weight of the residuals of production.
WR_C = the weight of the residuals of consumption.

Two important conclusions follow. First, the weight (quantities) of the residuals discharged to the environment can only be reduced by a) reducing the weight of the resources and materials that are put through the consumptive and productive transformations or b) capture the residuals from the productive and consumptive transformations and recycle them through the system as resources. A second important conclusion is that the more stringent the restriction on discharging to one sink (say, water) the worse the ambient quality of the other sinks (say, air and land). The important point is that these sinks are interrelated, and it is not possible to regulate the ambient quality of all sinks simply by promulgating standards.

An additional principle, contributed by the discipline of economics, is that in most instances it is inefficient to control pollution completely. This can be seen by referring to Figure 2 where the optimal amount of pollution abatement is found at the point where the marginal costs of control and the marginal benefits of control are equal. This means the optimal point of control is just before the marginal costs of control exceed the marginal benefits derived from that control. This position maximizes the net benefits of pollution control. There are several instances in which this conclusion does not hold. The first is the case where the pollutant to be cleaned up is so toxic or harmful as to cause damages that border on being infinitely large. Another instance is where the costs of cleaning up the pollutant are themselves very large, perhaps bordering on being infinitely large (Baumol and Oates, 1993).

Figure 2. Incremental costs and benefits of pollution control



Where:

MCC = Marginal costs of pollution control in USD$
MBC = Marginal benefits from pollution control in USD$
Q* = Optimal quantity of pollution control
p* = Incremental price of optimal control

Well-crafted policies and regulations for the management of water quality will embody these two principles in straightforward ways. Such policies will contain explicit acknowledgement of the interrelatedness of waste sinks-air, land and water. They will avoid simple expedients that are not effective such as setting ambient standards for a single sink without further providing for implementations. Effective policies will also avoid, where appropriate, simplistic objectives such as zero discharge requirements that may be unnecessarily expensive.

Health.

Different uses require water of different qualities. Thus, for example, some industrial uses such as the manufacture of computer chips require water of the highest possible quality whereas water that is used for cooling or instream uses (such as navigation) can be of indifferent quality. While waters of differing qualities may be suitable for different uses the need to protect humans from waterborne disease is probably the most important challenge faced by water purveyors. In particular, waters used for drinking, cooking and human contact (swimming) must be of the highest quality so as not to cause or spread human disease. Waterborne diseases have long been known but many are still prevalent in various places around the global, including the western Hemisphere. The health effects of drinking contaminated water have been well documented and range from short term gastrointestinal diseases to longer term afflictions such as cancer and delayed neurological development. The availability of water of good quality is an essential ingredient for good health.

Water is sometimes called the universal solvent and thus virtually all naturally occurring waters are contaminated to some extent. Chemical contamination occurs naturally when water comes in contact with soil and/or the geological substrate. Naturally occurring contaminants are mainly inorganic and include arsenic, fluoride, iron, manganese, nitrates and radionuclides. These contaminants are generally found in higher concentrations in ground water than in surface water. Many of the naturally occurring contaminants are harmless to humans so long as their concentration in water is low. However, at some point the intensity and/or frequency of exposure results in adverse health effects. Other contaminants, arsenic is an example, accumulate in the body over time and exposures that are intense and frequently of some duration can result in cumulative body burdens which at some point become toxic and then lethal.

A contrasting source of chemical contaminants are those that are man-made or introduced into the environment by human endeavors and activities. These include chemicals found in domestic and industrial wastewaters; fertilizers, pesticides and other chemicals utilized in agriculture; mining wastes (tailings) and drainage from abandoned mines. Emerging contaminants are a major source of concern over water contamination. These are synthetic chemicals which are associated with new technologies or processes that have only recently been developed and maybe undergoing rapid and pervasive adoption. These chemicals are of special concern because little is usually known about their health effects and other side effects. In addition, emerging chemicals have, by definition, not been present in the environment before the resulting environmental interactions can lead to the release of chemicals that have not been seen (or perhaps even detected) before. The toxicity and other possible health impacts of such chemicals are themselves unknown. Emerging contaminants pose a threat to the populations of every country in the western Hemisphere. For some the capacity to assay such contaminants for regulatory purposes is inadequately developed or inadequately funded and/or managed. Even for countries with relatively advanced regulatory systems such as Canada and the United States the scale of efforts and methodologies for detection in order to evaluate emerging contaminants is totally inadequate to keep up with the new contaminants that emerge every day.

Chemicals, both naturally occurring and man-made, represent one important class of contaminants. The other is the class of biological contaminants. These include viruses, bacteria algae and protozoa. Some of the best known and most widespread of the water borne diseases are bacterial and include cholera, dengue, salmonella and, indirectly, malaria. These diseases are customarily associated with untreated wastewater. Emerging pathogenic bacteria that can be transmitted through water are a source of increasing concern. The need to devise effective methods of identifying and managing such bacteria either through prevention or treatment methods is an important scientific challenge of water quality professionals. Viruses that are the cause of disease are most frequently transmitted through contaminated wastewater, often untreated sewage. Some of the most important viruses are Norovirus, Rotavirus, Hepatitis A, Hepatitis E, Enterovirus and Adenovirus. These and other disease-causing viruses tend to be found in locales that lack adequate sanitation facilities altogether or where existing facilities are outdated or poorly operated. Outbreaks of water-borne bacteriological and viral diseases occur most frequently in rural areas and peri-urban areas that typically lack adequate sanitation. However, such diseases are also found in urban areas and there are also high-profile outbreaks in more developed countries. Both Canada and the U.S. have had serious incidents of water borne diseases in the modern era.

Throughout the Americas the percentage of urban populations with access to clean healthful water for drinking and cooking is high, exceeding 90% in most cases. The coverage is considerably lower in rural areas and in peri-urban areas which tend to be at the margins of major urban areas and have grown without adequate attention to water-related infrastructure. In North America coverage tends to be more adequate in rural areas but there are notable exceptions. Indigenous people, in particular, are not always well served. The situation with sanitation services is considerably less bright. For the vast majority of countries little more than half the population has access to adequate sanitation services. Improvements in the extent and effectiveness of sanitation services is likely the highest priority means for reducing the incidence of water-borne disease. One problem that has been encountered in the economically developed countries of North America is the failure to maintain and upgrade both water supply and sanitation systems. This problem is severe in the United States where significant efforts need to be made to upgrade and modernize water related infrastructure (Venktaraman, 2013.)

Global Climate Change.

The full implications of climate change for different locales and regions of the Americas remain uncertain. However, it appears likely changing climate will have impacts on water resources that might be severe. Protection and enhancement of water quality will likely pose management challenges everywhere in the hemisphere. It will be important to anticipate these as fully as possible and to be prepared to deal with them. The impacts on water quality will likely be quite variable and widespread. The increased frequency of extreme events will most probably result in an intensification of these processes. Droughts will lead to a greater concentration of known pollutants associated with impacts on public water supplies and biota and ecosystem communities. With less water available the same water sources will have stronger competition for use for example for both consumption and irrigation and in some cases for waste disposal. In contrast flooding brings in great quantities of sedimentation from increased runoff and extreme events such as hurricanes tend to change drastically hydrological flow systems exacerbated by former deforestation which cause sedimentation and siltation in rivers and lakes from the surrounding basins which in turn affects flow regimes.

This all means that certain contaminants such as metals, nutrients and certain ions which had formerly been stored in sediments can be released into the water bringing about problems with water quality for different uses and ecosystems. It is also well known that increasing temperatures in lakes and rivers can trigger the intensification of cyanobacterial blooms in more waterbodies as they begin to dominate the ecosystems due to their stronger adaptation to higher temperature. An increase in forest fires provoked by climate change or disappearance of permafrost as observed in Canada can lead to reconcentration of contaminants.

As agricultural uses of water resources now account for 70% of global consumptive use, growing population will place additional pressures on agriculture even as aridity increases in many places around the globe. This means that it will be especially urgent to husband existing water supplies and protect water quality.

CHAPTER III

SURVEY OF WATER QUALITY PROBLEMS

A. EUTROPHICATION.

Eutrophication is one of the most frequent and widespread environmental problems of inland waters in the world. It is a natural aging process of waterbodies that occurs slowly over extended time scales (ie geological); however, anthropic activities of the last century have accelerated this process. Excessive enrichment with nutrients from surface waters, mainly phosphorus (P) and nitrogen (N), necessarily leads to changes in the structure and functioning of aquatic ecosystems, such as increasing its biological productivity and deteriorating the water quality, among other consequences.

Virtually all the countries of the Americas experience some degree of eutrophication in their water courses and waterbodies. Eutrophication is often characterized as cultural, which means that the phenomenon is artificially established by an excess of nutrients in the waters that are discharged by agricultural and industrial activities instead of coming exclusively from natural sources. Various results include algal blooms that are sometimes toxic and deplete dissolved oxygen. Cultural eutrophication can make water unsafe for consumption and other purposes and can destabilize the aquatic ecosystem. The latter usually leads to the proliferation of algae, with the consequent release of toxins and the explosive growth of unwanted species.

The main sources of eutrophication in the Americas and the Caribbean come from untreated or inadequately treated wastewater; expansion of the agricultural frontier and the indiscriminate use of chemical fertilizers; urbanization of drainage basins; intensive breeding of cattle, pigs and poultry; increased aquaculture; construction of reservoirs; destruction of natural ecosystems and deforestation; and accelerated erosion in drainage basins.

A brief summary of the causes and consequences of eutrophication processes in the American continent will be presented next:

1. Point and non-point sources of pollution.

Point and non-point sources of wastewater have been identified as one of the main sources of pollution in the American continent, including the Caribbean islands. On the one hand, the lack of treatment or the inadequate treatment of wastewater from urban areas and industries, deposit a large amount of organic matter and various pollutants and nutrients to the tributaries of lakes and reservoirs that are later used as supply of drinking water to the population, all of which deteriorates water quality and can be significant risks to human health. Point sources emanate from an identifiable location, which could facilitate, to some extent, their mitigation and compliance with regulatory standards, unlike non-point sources, which are diffuse and introduce pollutants that are difficult to regulate directly, because it is impossible to identify their points of origin.

Point source discharge is a fairly common problem in the region. In Guatemala, for example, the direct discharge of wastewater to Lake Atitlán has been estimated at a rate of 407 liters per second, increasingly accelerating the eutrophication of waterbody. Likewise, in Nicaragua, the urban centers of the Xolotlán and Cocibolca basins introduce domestic wastewater without adequate treatment directly to both waterbodies and have accelerated diffuse pollution due to changes in land use in their basins caused by deforestation and conversion to pastures, thus deteriorating the quality of its waters. In South America, in Brazil there are notorious cases of eutrophication through the discharge of wastewater into continental waterbodies without having previously treated them adequately; only in the South and Southeast regions, 40% of the wastewater is discharged without any type of treatment in rivers, reservoirs, coastal lagoons and coastal regions. As a consequence, cyanobacterial outbreaks are frequent in inland and coastal waters. Similar cases are also reported in Colombia and Venezuela. Only in a few locations in South America could the point source eutrophication process be less severe, as in the case of the Brazilian city of Paraná, which treats around 70% of its wastewater, and the case of Chile, which it has a high proportion of treated wastewater (around 80%) before being discharged back into water courses.

On the other hand, non-point source pollution includes runoff from watershed lands that have been eroded, modified, or otherwise deforested; runoff from agricultural land containing the agricultural chemicals waste, including fertilizers and pesticides; stormwater runoff from urban landscapes containing all kinds of chemicals, including hydrocarbons and sediments. Controlling these non-point sources is more difficult, and generates a large part of the cases of eutrophication documented in almost all the countries of the region. For example, in Canada, the contribution of phosphorus derived from land use generates algal blooms that affect large areas of Lakes Erie and Ontario in the east of the country, and in Lake Winnipeg and other waterbodies of the western regions.

Other documented cases of contamination from non-point sources have occurred in Mexico, in all Central American countries, in Cuba, Venezuela, Colombia, Brazil, Argentina and in the basins of the Macrozones of the Central and Southern region of Chile, where the residues of the agricultural activities arrive by runoff to the waterbodies.

2. Agrochemicals and livestock and aquaculture waste.

The use of fertilizers in agriculture contributes to waterbodies causing their eutrophication by the runoff of large amounts of nutrients, mainly N and P. These cases have been documented in Canadá, the United States, México, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, Cuba, Colombia, Perú, Brazil, Uruguay, and Chile; in the latter country, wine-growing activities are added. Livestock activities also contribute with a large amount of organic matter and nutrients to waterbodies, as has been recorded in Chile and Uruguay. Likewise, waste from aquaculture and fish farming activities represent important contributions of nutrients; such is the case of those documented in the Junín region in Perú, where intensive fish farming is an important factor in the eutrophication process, particularly in the Habascocha, Tipicocha, Huascacocha and Pomacocha lagoons, which present eutrophic conditions.

3. Deforestation and erosion.

Deforestation in watersheds has accelerated in all the countries of the Americas. The loss of vegetation due to deforestation and urbanization, and the consequent erosion, prevent the retention of nutrients in drainage basins and lead to the transport of sedimentary materials and nutrients to waterbodies. For example, in Honduras, deforestation has increased the generation of sediment from erosion, while forest fires generate abundant ash and carbon residues, all of which reduce the volume of waterbodies and their ability to dilute nutrients, while ash residues can represent the entry of nutrients to waterbodies. This type of situation has also been reported in countries such as Brazil, Colombia, Chile and Panamá.

4. Impacts on aquatic ecosystems.

The excess of nutrients results in an excessive growth of phytoplankton and aquatic plants, which leads the ecosystem to an imbalance of respiration and photosynthesis, with loss of oxygen at night and supersaturation during the day. Excess biomass brings with it the decomposition of organic matter, which requires a large consumption of oxygen, eventually producing gases such as methane and hydrogen sulfide, causing bad odors and anoxic environments that prevent the normal development of aquatic fauna.

A high degree of development of macrophyte species has been recorded in eutrophied lakes and reservoirs of Central America, Brazil, Colombia and Venezuela, and the dominance of a few species of cyanobacteria, such as those belonging to the genera *Microcystis, Anabaena, Planktothrix, Oscillatoria* and *Cylindrospermopsi*s (now called *Raphidiopsis*) in waterbodies throughout the region. Eutrophication has reduced the diversity of species present in waterbodies, in which a few species of cyanobacteria, many of them with toxic strains, have become dominant, as has been documented in the southeastern region of Brazil.

In countries such as Honduras, El Salvador, Guatemala, Panamá, Colombia and Venezuela, the surface of many continental waterbodies have been covered by the macrophyte *Eichhornia crassipes*, which is a floating plant that can form large locks and islands in lakes and reservoirs. In Panamá, the presence of other macrophytes such as *Pistia stratiotes* (floating), *Eichhornia azurea* (rooted) and *Hydrilla verticilata* (submerged) has also been detected, while in Venezuela the floating aquatic plants *Pistia stratiotes* and *Lemna obscura* are also common.

Due to the problems of lack of oxygen at night, consequence of the invasion of lakes and reservoirs by aquatic vegetation and phytoplankton blooms, there have recently been numerous cases of fish mortality in Colombia, mainly in the Magdalena River, Betania reservoir, the Ciénaga Grande de Santa Marta and the Porce River. These problems have also been documented in Brazil and Venezuela.

The reduction of biological diversity represents another impact of eutrophication on inland waterbodies: planktonic communities have a low representation of taxa in phytoplankton and zooplankton, and dominated by few species that effectively occupy a wide spectrum of niches that monopolize available resources. Regarding trophic networks, it has been found that it is possible that the flow of energy, carbon and nutrients stored by phytoplankton, is mainly oriented to the detrital pathway and dissolved substances and that, therefore, the latter are the main carbon source for zooplankton.

It is clear that the impact of eutrophication significantly limits the totality of ecosystem services that these aquatic systems can provide, in response to the gradual loss at a spatial-temporal level of the potential of the water and hydrobiological resources that can be generated.

5. Cyanobacterial blooms and toxins.

A particularly insidious manifestation of eutrophication involves cyanobacteria, which are photosynthesizing bacteria, which are found naturally in terrestrial and aquatic habitats around the world. Under conditions that include extreme levels of eutrophication and featuring specific strains of cyanobacteria, the associated algal blooms release toxins that are dangerous to animals, some forms of plant life and humans. The potential for such outbreaks exists throughout the Americas and is an extreme case of the kind of contamination that severe cultural eutrophication can lead to, all of which constitute an additional risk to the human health, since in all the countries of the Americas there is a lack of monitoring in surface water aimed to detect toxins.

Blooms can occur for periods of various duration over hours, weeks or seasons, and their accumulation tends to be recurrent in the same waterbodies, as has been reported for Lake Coatepeque in El Salvador. As a consequence of the eutrophication process, in almost all the countries of the American continent frequent blooms of cyanobacterial species have been registered in lakes and reservoirs, many of them with strains with toxins.

Examples of these negative effects have been described in several of the American countries, such as the death of cattle in the Río Negro basin in Uruguay, probably associated with the ingestion of high concentrations of toxins after cyanobacterial blooms. The case that occurred during the month of April 2017 in the City of Villa Carlos Paz, Province of Córdoba, Argentina, when the environmental emergency was declared due to the advanced state of eutrophication of the San Roque reservoir, which caused blooms of the cyanobacteria of the *Microcystis* genus, which has a powerful toxin for humans and represents a high potential for danger to collective health, since this reservoir is the main source of drinking water to a population of over one million people. Likewise, in bioassays carried out in Guatemala, the toxic effect on fish of microcystin and anatoxin-a, toxins detected in blooms of cyanobacteria *Microcystis* sp. and *Dolichospermum* sp. in lakes Amatitlán and Atitlán respectively, all of which represents a serious risk to human health, given the human activities that take place around these lakes.

B. CHEMICAL POLLUTION.

1. Emerging contaminants.

In the past few years there has been great concern about emerging pollutants, which presence in the environment and their possible health consequences have gone unnoticed. These compounds are disseminated in the environment and have been detected in water supply sources, ground and surface waters, and even in drinking water. These wastes from pharmaceutical compounds not only affect biological processes in municipal wastewater treatment, but also exceed the limits for consumption of potable water..

Drugs that have been detected in the aquatic environment include anti-inflammatory analgesics, antibiotics, antiepileptics, β-blockers, lipid regulators, X-ray contrast media, oral contraceptives, steroids, bronchodilators, tranquilizers, and many more. In some countries, investi-gations have determined the presence of emerging pollutants at the entrance and exit of treatment plants, showing that their complete elimination is not possible; the problem is that its toxicity, as well as the toxicity in its metabolites, which in some cases can be even stronger, is unknown. Aquatic contamination due to antibiotics implies the development of resistance to them and thus presents a growing problem for public health. Also, when they reach hydrological systems, they affect ecosystems and the composition of organisms considerably. Today, emerging pollutants continue to be partially ignored in addition to not being monitored in many countries of the Americas.

There are regulations regarding pollutants in waters in the Americas, in Canada and the United States, but the practices are not enough to evaluate the list of toxic potentials that keep increasing every day. The situation in Latin America is still little discussed and potentially dangerous in the near future. In all the countries there are references to specific studies that demonstrate that a multitude of pharmaceutical waste are deposited into the hydrological system domestic and industrial wastewater. In México, emerging pollutants are reported in urban-industrial wastewater from Morelia and Michoacán. In Honduras, Guatemala, Costa Rica and other Latin American countries, hydrocarbons, pesticides, pharmaceuticals and personal care products are reported. Likewise, in South America all countries report serious problems of emerging pollutants given the high consumption of drugs by the population, in addition to hospital waste.

In this context, the limitations in the care of waterbodies are discussed, not only in the disposal of wastewater but also in sources of human consumption. It is necessary to increase knowledge about the origin, transformation and effects of this new generation of pollutants, in order to propose water treatment mechanisms to guarantee an ideal quality, without effects on human health and the organisms of the aquatic ecosystems.

2. Toxic chemicals substances.

Toxic chemicals are products whose manufacture, processing, distribution, use, and disposal represent a risk to human health and the environment. If these chemicals seep into the soil or water, they contaminate the water supply, air, crops, and domestic animals; they are also associated with human birth defects, abortions, and other types of diseases. It is reported that more than four million synthetic chemicals have been manufactured in the world in a fifteen-year period, and 500 to 1,000 new products are created each year.

Chemical accidents are associated with the leak, spill, explosion, fire, of dangerous substances. Many examples of this type of accidents are mentioned in the world literature. In Latin America, many cases are known: San Juanico and Guadalajara in México, Goiânia in Brazil, the constant oil spills in Colombia due to terrorist acts, and the case of the highway from Caracas to Valencia in Venezuela. On the other hand, in all Latin American countries there is a great agricultural activity such as banana, rice fields, sugar cane, potatoes, corn, cotton, among others, in which millions of tons of pesticides and herbicides are used. Another source of toxic pollutants is widespread mining throughout the continent. It should be mentioned that the use of glyphosate to combat coca crops, on which there is no scientific consensus about its toxicity. Likewise, disasters are reported due to mercury contamination in the Bay of Cartagena, Lake Maracaibo, Lake Managua, Bahías in Brazil, and in Guatemala ingestion of seeds with mercury-based fungicides. In 2002, Canada and the United States released and transferred about half a million tons of chemicals known or suspected to cause cancer.

In everyday life, regular exposure to toxic chemicals has increasingly become a health concern. Unfortunately, many of the products that are used for health contribute to generate dangerous exposures; these include cleaning products, disinfectants, clinical supplies, formaldehyde, and solvents used in laboratories. Among the most common toxic substances in food and water are mercury, arsenic, hormones, dioxins, lead, benzene, cadmium, mercury, and pesticides, among others. In summary, the entire population in the Americas, and especially Latin America, is permanently exposed to health and mortality problems due to the toxic chemical's exposure; it is a silent disease. It is a serious problem that people are unaware of, there is very little regulation and lack of government intervention.

3. Acid rain.

The causes of acid rain are linked to sulfur dioxide and nitrogen oxide produced by the industries, the automobile fleet and emissions from volcanoes. It is a worrying problem because this type of pollution usually occurs in urban or industrial areas where most of the population is concentrated (**Figure 3**). Acid rain can also be caused by natural sources such as volcanic eruptions and earthquakes. Air pollutants can cause respiratory diseases like asthma and chronic bronchitis. Acid rain also damages automobiles paint, buildings and dissolves calcium carbonate, damaging monuments and buildings. It is also the cause of damage to nitrogen-fixing microorganisms in water and soil; a very important indirect effect is the impoverishment of certain essential nutrients, that plants need and they become more vulnerable to pests. In lakes and rivers, acid rain causes a drop in the pH level below 6.0, known as acidification, which can cause severe changes in aquatic ecosystems at all trophic levels.

The impact caused by acid rain could be mitigated in part by switching to renewable energies such as solar, wind and hydro. In large cities, automobile traffic is the main cause of acid rain; therefore, many cities in the world are switching to public transportation and electric vehicles.

In Latin America, the population increase brings as a consequence an increase in energy consumption, a greater number of motor vehicles and industry growth. Specific meteorological variables such as temperature, humidity, wind, precipitation, atmospheric pressure and solar radiation, condition the dispersion and chemical reactions of pollutants. This phenomenon is frequent during winter and explains the high concentration of pollutants in some cities such as México, Santiago de Chile and most of the large Latin American cities. In 2019, Guanta in Venezuela was considered the invisible city that lives under a toxic cloud; the same is said of Lima. In México there is a concern that acid rain could damage Teotihuacán and other historical monuments. São Paulo, an industrial city notorious for its high levels of air pollution, where there were deformations in newborn babies and serious generalized health problems, but since the late 1980s initiatives have been developed to improve the environment and have managed to reduce pollution levels up to 90%. In Colombia, IDEAM (Institute of the Environment) has been in charge since 1998 of managing the acid rain monitoring system in the country. In La Paz there are conditions to produce acid rains caused by the Internal Combustion Power Plant located in Libramiento Santiago Oceguera. In summary, all the big cities in Latin America have all the conditions to receive acid rains.

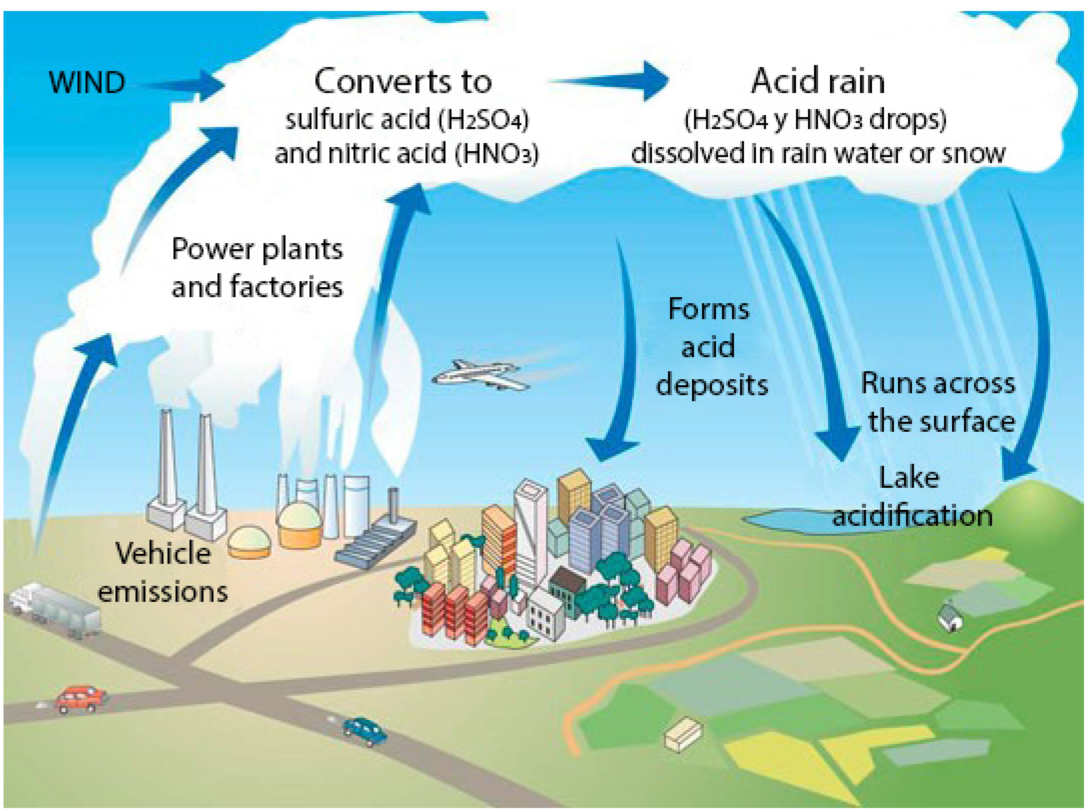


Figure 3: Acid rain cycle. Source: (https://cuidemoselplaneta.org/que-es-la-lluvia-acida/)

These rains also acidify natural waters, especially lakes, where they create a chemical imbalance due to adverse effects on aquatic habitats that can lead to biological diversity loss. The increase in acid rains can frequently have an impact in places far from their emission sources, which affects the will to improve the offending discharges. For example, emissions of sulfur and nitrogen oxides from southern Canada and the northeastern US caused precipitation with a pH below five in areas of the Canadian Shield where thousands of lakes and soils poor in basic cations are located that can normally neutralized the acid rain in less sensitive areas (Schindler *et al*., 1981).

4. The salinization of rivers.

The salinization of rivers refers to the process of increasing the content of dissolved salts of different types and origins transported by its water. This increase in dissolved salts in the river flow worsens their quality and puts at risk this water different uses, such as irrigation and purification, but it also conditions river ecosystems. Human activities can cause uncontrolled discharge of salts, changing the quality of the natural water of a river. Mining activities are the ones that contribute the most salts to rivers and other waterbodies. The long-term consequences of this salinization in river waters are still unknown, but it is clear that freshwater flora and fauna suffer enormously when the water that circulates multiplies the salinity value by more than 10 times.

The rapid warming of the Arctic causes it to enter a new climatic state. As the total area of ice and snow cover shrinks, the amount of solar energy that is reflected back into space also decreases, causing the planet to get even hotter. Simultaneously, this causes more fresh water to incorporate into the oceans, therefore its level rises bringing intrusions of salt water in the river mouths. This is already being observed in many parts of the earth, causing great damage to agriculture and aquatic flora and fauna.

Studies of lakes in North America show that lakes are being salinized by the salt used to melt winter ice and snow. In México, high salinities of the Santa María-Río Verde hydrographic system are reported. It is estimated that Colombia has 14 million hectares degraded by salinization. Currently there is a protocol to identify and evaluate soil degradation by salinization. In Venezuela, due to the damming of the Caño Mánamo, this area could be seriously compromised in its productive potential due to the salinization of the swamps. On the Peruvian coast there are drainage and salinity problems due to saline intrusion from the sea into aquifers and rivers; most are related to geomorphological features. In Bolivia, the salinization process of river and soil waters, mainly in the Desaguadero basin, is due to human activity associated with mining. Likewise, in the southern sector of Lake Poopó, salt crusts and diversity loss of wild bird species and fish population loss are observed. The salinity problem in Chile affects irrigation and crops in the Lluta and Azapa valleys in the north and many other regions of the country. Argentina also reports numerous agricultural regions affected by salinity. In Brazil, the analysis of groundwater samples above and below a dam has shown that both have a high degree of salinity for irrigation purposes, therefore it is only recommended the use for halophyte crops.

In summary, in all the countries of the Americas serious problems of salinity of soils and water are reported due to agricultural practices and pollution of domestic and industrial origin. A single measurement of electrical conductivity would reveal the degree of complexity of this situation. Finally, it is expected that in a few decades, all river mouths will be strongly affected by the rise in sea levels due to global warming of the planet.

5. Mining and other industrial wastes.

The most relevant impacts of open pit mining are damage to the earth's surface, air pollution, contamination of surface water, damage to underground aquifers, impacts on flora and fauna, conflicts between communities and mining companies, land misuse and visual changes (**Figure 4**). After completing the exploitation, huge craters remain in the area, affecting negatively the surrounding landscape and resources. Underground mining is dedicated to the exploitation of resources below the surface of the earth. One of the advantages of this is the reduction of contamination in the nearby areas of the mine; the disadvantages of underground mining compared to open pit mining is the prolonged exposure of workers to toxic gases and tunnel collapses.

Figure 4: Example of small-scale mining in the Amazon.
Source: www. mineria+en+amazonas+&oq=mineria+en+amazona

Today it is estimated that more than 500 thousand small-scale gold miners carry out operations in the Amazon. Most of them are local dependent on large companies. Currently, at least 30 rivers are affected by small-scale mining in the Amazon.

In the Americas, mining constitutes one of the most serious environmental and social problems on the continent. In Canadá, the mining industry has a difficult road ahead when trying to convince very skeptical sectors of Latin American society about the advantages of the activity. Canadian mining generates jobs, investment and foreign exchange for Latin American countries. In the United States, the Earthworks Mining Watchdog Report reveals that each year around 17 billion gallons of contaminated water will be generated by 40 existing Hardrock mines (eg, gold, copper, uranium mines). Water treatment due to the activities of these mines is said to cost as much as $67 billion per year. In Latin America the situation is dramatic. Mining exploitation is proposed in Central American countries as one of these alternatives, despite the fact that it is widely demonstrated that it is one of the most polluting industries that exist in the world, since its production process uses highly dangerous elements such as cyanide, cadmium, copper, arsenic and lead, among others. In México there are socio-environmental conflicts and open pit mining in the Sierra Norte de Puebla. México is the second country in Latin America, after Perú, with the highest number of conflicts, with Puebla and Oaxaca being the states with the highest number of cases.

In Perú, on June 2, 2000, there was a spill of 151 kilograms of elemental mercury, which caused intoxication in around 1,200 people in addition to the contamination of rivers, local flora and fauna. In Venezuela, in the States of Bolívar and Amazonas, for approximately 25 years it has been shown that mining has caused great environmental impacts, generating sources of mercury contamination, which has shown a considerable increase in recent years. In Colombia, environmental impacts are associated with the felling of forests, contamination of rivers by sediments, mercury and cyanide due to mining activity. Studies carried out by several universities have shown mercury concentrations in fish, human nails and hair up to 50 times higher than the permissible limits. The areas most affected by gold mining are Chocó, the inter-Andean valleys and the Amazon. In Bolivia the mineral deposits of traditional exploitation generally correspond to the type of hydrothermal deposits. The main danger of mining exploitation for the environment in traditional areas comes from the contamination of rivers and groundwater tables by the acidic waters of mines. In Chile for 50 years the Ensenada de Chapaco has received mining tailings from an iron processing plant. In Argentina, the Veladero gold mine, which operates in the open pit at an altitude of more than 4,000 meters in the Andes mountain range, registered in 2015 the largest mining disaster in history: the spill of a million liters of cyanide water into the Potrerillos river.

Industrial wastes are those that come from the manufacturing, transformation, use, cleaning, maintenance or consumption processes that are generated by the industries. Used industrial oils, contaminated packaging, solvents, paints, batteries, batteries, contaminated plastics and containers that have contained dangerous substances, among others, are some examples.

Treatment and disposal are time consuming, as each of these wastes requires special treatment. This is one of the great challenges for governments orientated to achieve improved protection of environmental resources.

6. Natural contaminants.

The overexploitation of aquifers is exacerbating the problems of natural water pollution in many areas subject to water stress. The levels of fluoride, arsenic and other chemical compounds that are harmful to health affect millions of people around the world and are causing serious sanitary problems. Fluorine is found in all-natural waters to a greater or lesser extent; generally, most fresh water does not contain more than 0.3 mg / liter. It is an essential micro mineral for the human body, since it has an essential function in the formation of bones and the maintenance of dental enamel. However, ingested in excess is very harmful. Eating or drinking an excessive amount causes fluorosis, a disease that alters the development of the bone, dental, nervous system and problems with pigmentation in the skin. Also, arsenic, the most aggressive natural pollutant and the WHO considers it one of the most worrying public health problems. According to this organization, the natural contamination of groundwater by arsenic affects more than 140 million people in 70 countries on all continents. About a third of the arsenic present in the atmosphere comes from natural sources such as environmental reactions, biological activity, volcanic emissions, and the rest comes from a wide range of anthropogenic activities. It should also be mentioned the contribution of pollutants made by volcanic activity present in all the countries of America, especially the Central and South American countries. The plumes in a volcanic eruption contain many gases in addition to ash, including water vapor, sulfur dioxide, chlorine, hydrogen sulfide, and nitrogen oxides.

In Canadá, petitioners denounce that “the government is failing to effectively enforce the Canadian Fisheries Act, with regard to the runoff into surface and groundwater of toxic substances such as arsenic, iron, and copper from settling ponds in Northeast Alberta” (Petsko, 2019). In the United States, the Environmental Protection Agency -EPA has regulated the laws on arsenic. The Comarca Lagunera, located in the northeastern part of México, have reported since 1963 high concentrations of arsenic in the soil, rivers and underground water. According to the 2019 WHO observatory, the Central American region is at levels of 81 to 200 mg / L. In Colombia, the National Institute of Health reports a risk profile for arsenic in rice crops. Arsenic is naturally present in high levels in the groundwater of various countries, mainly Argentina, Chile, Bolivia and in almost all Latin American countries and is due to the dissolution of the geological medium close to mineralized structures, alterations by hydrothermal processes, which are usually in the proximity to tectonic structures which reaches groundwater through faults and fractures.

C. BIOLOGICAL AND OTHER NON-CHEMICAL CONTAMINANTS.

Biological and other non-chemical contaminants are important due to their special impacts on aquatic ecosystems and the sources of human consumption of water. The focus of this section is on a subset of these pollutants and includes consideration of the impacts on surface water of invasive species; sedimentation, due to deforestation; and microbial contaminants, both bacterial and viral. All of these have impacts on the economy for purification of water (higher costs for treatment), treatment of wastewaters, and ecosystem services.

1. Invasive species.

Due to the accelerated increase in global transport, organisms have been inserted into new ecological habitats and especially in aquatic environments. The invasion of non-native species frequently results in an explosion in their numbers due to the absence of natural predators in the food webs of the invaded habitats. This has caused significant damage to the environmental integrity in aquatic ecosystems and is often attributable to modification of land uses, hydrologic flow paths, global warming, and other causes. Invasive species tend to affect trophic levels in the aquatic ecosystems which can lead to the extinction of species. These interventions have economic and financial impacts as with the increased costs occasioned by the need for cleaning and control programs. For example, the loss of native salmonoid species in the Great Lakes of Canada and the U.S. has been accompanied by significant economic losses.

The Great Lakes example is important and well known. The aquatic community of the Lakes has been irreversibly harmed and there have been significant economic impacts to the Great Lakes region. Evidence from Canada shows that:

"…the first of many problem invaders was the sea lamprey *Petromyzon marinus*, which is native to the Atlantic Ocean. It was observed in Lake Ontario as early as 1835, but Niagara Falls prevented it from entering other Great Lakes until it entered via the newly completed Welland Canal sometime in the 19th century".

It wasn´t until the 1940s that lamprey populations increased drastically and affected the food web in the entire Great Lakes systems and strongly influenced the fishing industry when fishery numbers were "reduced to 2% of pre-lamprey values". (IANAS, 2019).

It is important to note that even after the establishment of lamprey control programs it has not been possible to eliminate them entirely from the Great Lakes.

Another example from the Great Lakes are the Zebra mussels and Quagga mussels (*Dreissena polymorpha* and *D. bugensis*). These organisms were introduced in 1980s in ballast waters pumped from the bilges of transoceanic ships. The ballast waters carried, larvae, juveniles and adult mussels. These organisms create significant damage by clogging intake structures in power stations and water treatment plants and by complicating the operation of locks and other aides to navigation in waterways. Zebra mussels have also arrived in other lakes in Canada and the USA. These mussels filter water more intensively than native species and excrete nutrients to the bottom of lakes causing multiplication of benthic algae such as *Cladophora* which form mats resulting in taste and odor problems (Hecky et al, 2004). All of these invasive species have harmed the aquatic community in the Great Lakes in which water quality is now irreversibly different from its original, pristine state.

2. Sedimentation and Deforestation.

Surface waters are the receiving bodies for contaminants resulting from the transport of materials occurring in their respective watersheds. Sedimentation is the result of changes and destruction of landscapes that intensify erosion. The sediments from erosion are transported from the watershed to the receiving waters where they can damage and/or diminish breeding areas. Excessive sediments that enter surface waters can also lead to diminished water quality and render the receiving waters unsuitable for human consumption and other uses such as irrigation. Sedimentation also affects the life span of reservoirs which act as settling basins. Rates of sedimentation in the western Hemisphere have increased almost everywhere in the last decades. Much of this is due to the conversion of relatively undisturbed lands, some of which were forested, to agricultural and grazing uses. Overgrazing and careless agricultural practices can lead to increases in run-off that, in turn, leads to increases in the rates and quantities of sediment transport into surface waters and coastal sea areas.

Reports from the 21 countries of the Americas cite problems of sedimentation affecting water quality. Most is caused by increasing deforestation rates. For example, in Nicaragua land use changes that follow rampant increases in deforestation in the last decades have contributed to sedimentation of surface waters and coastal areas with wetlands. The country lost almost 50% of existing forest coverage between 1983 and 2015 which has meant a loss of 1.4 million hectares of national territory. One result is the drastic destabilization of the hydrological systems. In Brazil there has been a great loss of forest coverage due to advance of the agriculture frontier and development of agroindustry. The impacts are especially pronounced in the central western portion of the country. Similarly, in Colombia the expansion of agriculture with monocultures and pasture lands have contributed to deforestation of 73% of the forested lands. Throughout the country deforestation activities have also resulted in removal of riparian vegetation which has contributed even more to deterioration of water quality.

Water is an all-round indicator of environmental quality since “it is directly influenced by the water regime to which ecosystems are subjected” (IANAS, 2019). Water volumes and flow are also affected by deforestation. In the Peruvian portion of the Amazon basin the massive deforestation has brought a great loss of biodiversity and adverse impacts on other natural resources. This has led, in turn, to increased costs of water treatment for potable uses and has also limited available water sources for irrigation. This latter problem is due not only to increases in sediment but also increasing salinization which makes the water progressively less suitable for use in irrigated agriculture. In Mexico, deforestation is reported to be “… omni present and contributes to sediment loading and erosion. It is more extensive in the south where 95% of the original forest has been eliminated.” (IANAS, 2019). There are other important examples that illustrate how erosion processes caused by deforestation can also lead to increases in discharges of pesticides, fertilizers, and their residues to water bodies. It should also be noted that climate change by altering the frequency of extreme droughts and floods can exacerbate erosion processes and fundamental changes in hydrology with resulting increases in rates of sedimentation and enhanced discharges of other contaminants.

To combat all of these adversities multiple efforts will need to be made with programs of reforestation in key areas of watersheds. In addition, programs that focus on the restoration of riparian forests are also needed.

In response, strong reforestation efforts are being made in some countries of the western Hemisphere. Cuba, which has historically lost more than 80% of its forested watersheds, has restored up to 50% of them and reforestation efforts continue. Grenada in the caribbean has strong and effective legislation that protects the quality of run-off from upland watersheds where most surface water supplies originate. Peru has developed significant plans for restoration and protection of watersheds. (IANAS, 2019). Other countries which have suffered extensive deforestation will need to develop and engage in similar plans in the future.

3. Microbial Contamination.

In past decades great strides have been made in providing urban water supplies that are free of microbial contamination and other pollutants. This is attributable largely to the wider construction of water purification facilities. In many countries over 90% of the population has access to clean water for drinking and other household uses. Despite this progress much remains to be done. The last outbreak of *Vibrio cholera* in 1991 affected most Latin American countries and underscored the need for more and better water purification facilities and wastewater treatment plants. While significant progress has been made in delivering safe drinking water many countries are without adequate wastewater treatment facilities. Microbial contamination continues to be a problem in some urban sectors and especially in rural and peri-urban areas where water and wastewater treatment facilities are often absent. There is also an ongoing threat posed by bacteria, viruses, and parasites which sometimes develop resistance to existing purification methods. In addition, the absence and failure of maintenance programs and renewal to facilities is frequently a cause of contaminations that are harmful to humans and lead to deterioration of sanitary conditions. It should also be noted that many countries report that monitoring programs are poorly designed or absent. This means that source waters are sometimes not assayed and that breakdowns or lack of performance of treatment plants go undetected.

Many countries have reported that microbial contamination impacts public health because there is **not continuous access** to potable water. There are several causes. First, households often store water in vessels that do not meet sanitary standards. Second, delivery of water in motorized tankers resulting in contaminated water because the tanks do not meet sanitary standards. These situations often result in the outbreak of serious disease. For example, in Panamá it has been estimated that 88% of diarrhea cases are due to unsafe storage of water and deficient hygiene in handling of water in households. Improving continuity of access to water could reduce between 6 and 21% of morbidity due to diarrhea (IANAS,2019).

In many countries of Latin America, rural areas experience problems of microbial contamination where the water supply is dominated by manually constructed wells. Often these are found on farms and in small communities. These wells lack adequate protections from surface runoff which can bring fecal matter from pastures, stables and poorly built latrines to wellhead areas. Outdoor defecation still exists in some rural areas.

A majority of countries in the Americas report that surface and groundwaters, including those in coastal areas, have high levels of microbial contamination.

"Microbiological contamination has been detected by water quality monitoring programs where the presence of pathogens has been found through fecal contamination indicators, fecal coliforms and *Escherichia coli* in almost a third of the rivers in Africa, Asia and Latin America, entailing a health risk for millions of people" (UNEP, 2016).

The affected hydrological systems are contaminated by runoff which transports fecal material from surrounding areas. For example, in El Salvador, the Ministry of Environment and Natural Resources reports that between 2011 and 2017 88% of the rivers received quality evaluations ranging between irregular to extraordinarily bad due to high concentrations of fecal coliforms. In Costa Rica, almost half of the urban rivers were found to have high concentrations of fecal coliforms in the metropolitan area of San José.

In many countries of the Americas the focus of water quality evaluation is almost exclusively on bacterial contamination. There is limited information on the extent of viral contamination in most countries due to the absence of monitoring programs that detect viruses. For example, in Ecuador and other countries rotavirus has been related to acute diarrheal disease. Hepatitis A and E viruses have been detected in surface waters in areas where there is a total absence of urban wastewater treatment systems and where there are discharges from farms raising pigs and other livestock types. Other viruses such as Astrovirus, Norovirus, Coxsackie virus, Enterovirus, Polioviruses, Adenoviruses and Echoviruses have been detected, where water has been found to be the vehicle and possible cause of different pathologies (IANAS, 2019). Similarly, Protozoans such as *Cryptosporidium* spp., *Giardia lamblia, Entamoeba histolytica* and *Balantidium coli* are known to be present in many waters as are Metozoans, *Schistosoma* spp. and *Dracunculus medinensis*. Helminths such as *Coccidio* sp., *Hymenolepis* sp., *Trichuris* sp., *Ascaris* sp. and *Oxiuros* sp., known water-borne human pathogens, are prevalent in some Latin American countries.

As noted elsewhere, monitoring is essential for assessing the quality of different waters and for providing feedback on the efficacy of water quality management programs. Virtually, every country in the Americas has identified improvement of monitoring systems and monitoring protocols as among their highest priorities for improved water resources management. Monitoring programs are needed to assess the performance of purification systems as well as source waters. Improved monitoring is needed to detect bacterial pathogens implicated as causing diseases with high mortalities such as *Salmonella typhi, Helicobacter pylori* and *Leptospira* spp. *Helicobacter pylori* is also known to occur in waters that move through pipes with biofilms and wastewater. Monitoring for viruses and parasites should also be included as absent in many countries. There is also a need to improve water quality monitoring in potable water and aquatic recreation areas by including viruses and parasites. The urgency for adequate monitoring should not overshadow the closely related need for increased numbers of improved water and wastewater treatment plants. Such plants should be adaptable so as to deal also with emerging problems of water quality. Special attention should be directed to peri urban and rural areas.

4. Importance and problems of adequate sanitation for urban and rural areas.

Needs for sanitation facilities and wastewater treatment have always had second priority compared with needs for safe drinking water. Nevertheless, it is now clear that adequate sanitation plays a key roll in securing better water quality. Worldwide increases in population, urbanization, industrialization, and expansions of agricultural uses of land emphasize the urgency of providing more comprehensive treatment of wastewaters. Also, declines in water quality are accompanied by increases in the costs of construction and operation of wastewater treatment systems. Changes and increases in contaminants demand new attention to better the design and functioning of treatment plants. As mentioned above every crisis usually brings improvements for example the *Vibrio cholerae* outbreak in Latin America in 1991 brought changes with the introduction of more wastewater treatment plants. Improvements were also made through the training of wastewater plant operators and better maintenance regimes. Also, there were new improved designs introduced for the treatment process. Despite these improvements many countries of the Americas lack full coverage of sanitation in urban areas and in many cases attendant pollution of receiving water bodies has been observed due to deficiency in treatment and maintenance. The provision and operation of

Latin America and Caribe Drinking Water and Sanitation in Urban Areas - 2017 % population							
Drinking Water			Sanitation				
At least basic	Safely Managed	Piped	At least basic	Safely Managed	Wastewater Treated	Sewer Connections	Open Defecation
99	82	96	91	37	37	77	<1
Drinking Water and Sanitation in Rural Areas - 2017 % population							
88	42	75	70	-	8	18	9

Table 1: Drinking water and sanitation in Urban Areas Latin America and Caribbean - 2017, % population. (JMP, 2019)

sanitation facilities in peri-urban and rural areas remains a critical problem, even in countries where urban coverage is good (Table 1).

Latin American countries are not on track to fulfill the sustainable development goals for sanitation of wastewaters in urban and rural areas. In urban areas it is a fact that 20% of wastewaters do not receive any primary treatment. The Central American countries have a level of urban basic sanitation ranging from 79 to 92% but the connections to sewage systems lie much lower between 28 and 73%. South America has a basic sanitation ranging from 57% to >99% but connections to sewage systems lie between 62 to 98%. There are little data on treatment plants with secondary treatment, but coverage appears to range between 15 and 47%. Chile is an exception with coverage of 81%. It is important to mention that data on sanitation coverage does not always reflect (JMP, 2019) the extent to which water quality is being maintained. The widespread presence of septic tanks in many Central American countries and the presence of vertical septic tanks in the Dominican Republic results in the contamination of some groundwaters that are the source of public water supplies. Also, in Central America oxidation lagoons treating domestic wastewaters account for the discharge of partially treated waste into surface waterbodies. In the southeast region of Brazil around 40% of wastewaters are deposited into receptor waterbodies without any treatment. Treatment plants that have low efficiency and little maintenance predominate and continue to contaminate receiving surface waterbodies.

Rural areas in Latin America are especially deficient in the sanitation of wastewaters, where only 70% of the population has basic wastewater treatment and sewer connections are extremely low with an estimate of 18%. Rural areas can still be found with no wastewater management at all where outdoor defecation can still be observed. These are usually inhabited by poverty-stricken people who have no means of improving the sanitation situation.

5. Solid Wastes.

Almost all of the countries of Latin America and some Caribbean Islands have solid waste disposal problems. Solid wastes, whether widely dispersed or concentrated cause pollution of drinking water sources and other waters. The lack of effective programs for solid waste collection and disposal in adequate sanitary landfills as well as adverse cultural habits contribute to this phenomenon. The inadequate disposal of urban solid wastes and untreated industrial residues in garbage dumps leads to contamination of ground and surface waters due to leaching processes. There are instances where for example metal residues have reached ground and surface water sources from these deposits. Precipitation and run-off can accelerate these processes.

In most countries in Latin America, organized sanitary landfills with specialized treatment for special wastes are not frequent.

"Municipal landfills receive industrial and domestic solid waste that has not been classified, where it could affect groundwater or reach runoff water and subsequently be discharged into surface water." (IANAS 2019).

Leachates from landfills are a source of ground and surface water contamination.

"Municipal wastewater and solid waste from the largest cities in the country-such as the metropolitan Region of Guatemala-are deposited in Zone3 of Guatemala City, which has no leachate collection or treatment. And in the remaining 333 municipal capitals there is an absence of control of leachate from solid waste deposits." (IANAS, 2019).

There are few facilities designed for the specialized treatment of hospital and hazardous waste in most countries. It has been observed in the last decade that antibiotics are widely distributed in rivers, lakes and sediments of these waterbodies showing the great need for special treatment of solid wastes from pharmaceutical industries, hospitals, intensive livestock husbandry installations, meat, pork and chicken processing plants and more.

Many coastal areas throughout the Americas have been transformed into floating reserves of garbage mostly plastics. A few countries have begun to collect recyclable materials and develop companies that will recycle paper, plastic and glass. (Styles, 2015).

D. GROUNDWATER.

Groundwater presents some special challenges if the quality of the water in specific aquifers (groundwater bodies) is to be maintained. The fact that groundwaters lie underground and are unseen poses difficulties in making qualitative assessments. Groundwater pollution is almost always attributable to non-point sources which are difficult to manage and control because community action of some type is virtually always required. When groundwaters are extracted in an individualistically competitive fashion the aquifer in question become prematurely exhausted - either physically or economically or both. This fact means that coordinated management of groundwater extractions from an aquifer will usually be a pre-condition to successful management strategies to protect quality because overdraft means that both the capacity to dilute wastes and the limited capacity to process them chemically and biologically are reduced. Beyond the issue of managing extractions, groundwater quality is difficult to manage because the sources of pollution are usually diffuse. There are often multiple extractors who operate independently of each other in the absence of management and, as has been shown, groundwater is much more expensive to clean-up once it has been contaminated than it is to prevent contamination in the first place.

Groundwater as a resource can have distinct advantages over surface water. Its availability tends to be buffered through natural storage and hence its immediate availability is not as directly dependent on rainfall and runoff as surface water. This explains why the availability of groundwater in times of drought is particularly advantageous. The occurrence of groundwater in the western hemisphere is uneven; different countries are endowed with different quantities and different areas within each country are differently endowed. 90% of the water supply of Costa Rica comes from groundwater while that source accounts for as much as 40% of the available supply in Argentina, México and the United States. A number of other countries, including Colombia and Perú have endowments in the 15-20% range and several have very small endowments such as Panama, with 3%. Other countries with very small endowments include a number of island nations in the Caribbean; for example, in Grenada only about 5% of the population´s water needs are covered by groundwater. Irrespective of the magnitude of its groundwater endowment, virtually every country in the Americas needs to do a better job of managing its groundwaters. Countries with large or medium endowments will likely be more focused on the protection of these endowments as they are needed to address current water demands and maybe a badly needed source of additional supply in the future. Even countries with small endowments will need to attend to the protection of the groundwaters. Panamá, for example, currently relies virtually exclusively on surface water. The Panama Canal is a very large user of surface water and that use is important to the country economically. Simultaneously, competition from rapid urban growth and economic growth will probably require the country to utilize its groundwater in the future as the last source of internal supply. Thus, it is not too soon to manage the quality of groundwater in order to protect an important source of future supply.

The threats to groundwater quality are numerous. They include quality degradation from salinization and sea water intrusion, threats posed by chemicals in the natural environment which may leach or otherwise invade a groundwater body and threats posed by humans, particularly from industry, agriculture and inadequate sanitation. Many coastal aquifers in the Americas are threatened by sea water intrusion. Such intrusion is almost always driven by overextraction from the aquifer which in turn accentuates the pressure gradient between seawater and fresh water causing sea water to intrude. Once this has occurred it is difficult to clean-up and may be difficult to stop. Success has been had in some instances by injecting freshwater into the groundwater formations to restore and/or increase the hydraulic pressure to the point where intrusion stops, and saline waters maybe driven seaward, thus restoring to some extent some portion of the contaminated aquifer. In the future rising sea levels associated with climate change are anticipated to increase the extent and intensity of sea water intrusion in many coastal aquifers throughout the Americas.

Contaminants of groundwater include bacterial contaminants, organic contaminants and inorganic contaminants. The latter group includes substances that are naturally occurring with contamination caused both as a consequence of direct contact between the groundwater and the geological substrate and because of natural transport processes. Arsenic, fluoride, boron and mercury are among the most common naturally occurring contaminants. Salts of nitrogen and chlorine are also naturally present in many groundwaters. Some aquifers have been salinized historically and the waters therein are unsuitable for many uses unless desalinated. In México problems with arsenic and fluorides in groundwater have been partially alleviated utilizing techniques such as reverse osmosis. This type of clean-up can be quite expensive but is attractive in which there are no alternative sources of potable water.

The most common source of groundwater contamination is human activity, and it includes biological contamination and contamination from both inorganic and organic chemicals. Pollutants can be introduced to groundwater directly, through wells, or more indirectly through leaching and other transport processes. Agricultural chemicals and their residues are found in the groundwaters of most countries where agriculture is practiced. Among these are fertilizer residues, most of which are inorganic, and pesticide residues, most of which are organic. These are frequently introduced by the excessive application of fertilizers and pesticides. Establishment and enforcement of best management practices can ameliorate the continued introduction of these contaminants. Some of these residues are persistent. Others, such as nitrate nitrogen, are expensive to clean-up. A wide variety of pollutants can be introduced due to incidental wastewater discharge. Pollutants introduced in this way include pathogens, heavy metals and a wide variety of chemical compounds that emerge from industrial processes. Mining wastes which are subject to leaching and to surface transport are also common throughout the Americas wherever mining is practiced. These include metals and metalloids, many of which are highly toxic even at low concentrations.

Regulation of groundwater quality has its own set of difficulties. It begins with adequate monitoring protocols to identify where there are problems and the qualitative nature of the problems. Monitoring is expensive and is not a focus of public or political interest. Yet, it is essential. Contamination that occurs at the well-head is attributable to poorly designed and constructed wells and/or the direct introduction of pollutants into the well itself. Such pollution can be readily controlled through the enactment and enforcement of well construction standards and the imposition of well head management programs. Such programs, when well designed, regulate the care of land surrounding well-heads and the kinds of materials that can be stored and used in the vicinity of well heads. In these instances, polluting activities can be treated with standards and other regulations that are commonly applied to point sources of pollution.

Regulation of pollution that comes from beyond well heads is complicated by the fact that much groundwater pollution is the result of non-point source discharges. Such discharges are diffuse, and it is frequently impossible to attribute them or parts of them to a single source. In most instances, successful management of such non-point source pollution will require communal action that includes all agents who could be responsible or potentially responsible for contaminating an aquifer. Examples of such arrangements include local districts – which function as local, limited units of government; voluntary associations; and programs of regulation imposed by regional or nation governments. The latter arrangements usually suffer from the fact that polluting activities may differ from place to place and require very different sets of regulations. In such circumstances it is hard to make regulations both flexible and effective. The institutions selected to take management responsibility will usually develop programs of best management practices and these must be enforced to be effective. Such practices typically help to prevent the excessive application of agricultural and other chemicals. They also prescribe the appropriate treatment to be accorded to other materials and in some cases ban certain activities and materials from lands overlying the aquifer in question.

Taken as a whole the groundwaters of the Americas are not well managed or protected. There are, to be sure, examples of well managed aquifers but they are the exception rather than the rule. This is unfortunate because their nature as open access resources make them subject to qualitative degradation and/or premature physical and economic drawdown and exhaustion. For several reasons, groundwater is likely to become more important as a source of supply in the future than it has been in the past. Countries that currently rely on groundwater to a significant extent, Mexico is an example, will need to make every effort to protect its groundwater supply in the face of climate change which may reduce accustomed surface water supplies. Countries with more modest endowments of groundwater will need to act to protect their sources of supply in anticipation of increases in water demand fueled by population and economic growth. Panama is but one example where these circumstances will likely prevail. In addition, attention needs to be directed to aquifers that have already been degraded -either quantitatively or qualitatively- as likely candidates for restoration and rehabilitation as a means of augmenting available supplies for an uncertain future. The uncertainties of climate change include possible reductions in precipitation and runoff as well as their seasonal timing. The potential for declines in the availability of traditional water supplies also speaks to the need to protect and enhance groundwater quality throughout the hemisphere.

CHAPTER IV

WATER QUALITY GOVERNANCE, INSTITUTIONS, MANAGEMENT & PUBLIC POLICY

The maintenance and enhancement of water quality throughout the western Hemisphere is among the significant challenges on the water management agenda for the future. There are several reasons for this. First, deteriorating water quality reduces the supply of water available for many uses just as surely as drought. Second, throughout the Americas economic and population growth is likely to lead to growing demands for water. Third, the uncertainties posed by forthcoming climate change include the possibility of reductions in precipitation and run-off that would result in reductions in the availability of customary water supplies.

Climate change could have other adverse impacts on the water sector as well. What emerges is a general picture of the future in which water demands could continue to grow at the same time that water supplies are shrinking. In such circumstances protecting and enhancing water quality would have a high priority if only to prevent further reductions in water supply. In general, the countries of the western Hemisphere have not done well in constructing institutions and policies which protect water quality. Canada and the United States are among these countries. In this chapter several policy challenges are identified and a number of policy tools for managing water quality are described and assessed.

POLICY CHALLENGES.

Formulating policies for the management of water quality requires the acknowledgement of several critical factors that impact water quality.

The Need for Collective Action. Most surface waters and ground waters are subject to use by more than one individual. The resources themselves most often flow; they are fleeting resources. It is very difficult to vest property rights in fleeting resources because they can't be pinned down by location. This means that use whether it be for the corpus of the resources or for its waste assimilating capacities tends to be subject to the law of capture. When exploited in an individualistically competitive fashion premature exhaustion of the resource tends to be the outcome, whether it be groundwater, or the waste assimilating capacity of the surface water. Sticking with surface water quality, one person's waste discharges adversely impact downstream users and others seek preservation of the water quality. In theory, the resulting conflicts can be resolved through voluntary bargaining. That rarely occurs in real life. The result is that some collective institutional arrangement needs to be made to protect water quality in either its pristine state (which is rare) or at some level of quality that the community can live with for their needed uses. The resulting arrangements must be enforceable.

Without these arrangements there is little prospect of ever protecting water quality.

Monitoring. Monitoring is essential if water quality is to be managed. Without accurate monitoring it is not possible to know with any precision whether you have a water quality problem. And without accurate monitoring it is not possible to know when your efforts to protect or improve water quality are meeting the required goals. Water quality monitoring is inadequate throughout western hemisphere including in Canada and the U.S. Water quality monitoring is not politically interesting or popular. Nor is the need for it widely appreciated by the public. Yet attracting the political support needed to mount and conduct effective programs of monitoring is essential.

Sources: Point and Non-Point. The most familiar source of water pollution is from point sources. That is the pollutants enter a water course from the end of some pipe or in the inflow of some tributary. There is a point in space that can be subject to a discharge regulation. Point sources are relatively simple to regulate. By contrast, non-point sources are diffuse, there are multiple sources, but it is impossible to identify precisely where they came from. Examples include residual flows of fertilizer and pesticides from agriculture, storm flows from urban areas that have often been modified by paving, sediments that are entrained in runoff from eroding lands and waters flowing from abandoned mining sites. Non-point source pollutants are difficult to regulate since there is usually not a single point where regulation can be effective. Almost always regulation of non-point sources will require tools and strategies that are different from those that can be used to regulate point sources.

Managing Groundwater Quality. The prevention of groundwater contamination and sustaining good groundwater quality over time present special problems. Available research makes clear that it is almost always cheaper to prevent ground water pollution in the first place than it is to clean up pollution once it has occurred. Therefore, there is a strong economic incentive to maintain good groundwater quality. Problems arise because most, it not all, ground water pollutants come from non-point sources. Furthermore, the waste assimilation capacities of groundwater tend to be low in comparison with surface waters so the option of just waiting for the water to clean itself through dilution or assimilative chemical and biological processes is not generally very attractive. Where groundwater extractions are unmanaged and subject to non-point source pollution the resources can be economically or physically exhausted.

In the absence of effective management programs, it is unlikely that water quality can be protected because extractors have little or no incentive to protect the resource. Thus, management and regulation of groundwater extractions is generally a precursor to successful management and protection of groundwater quality. The available tools for such protection include well-head protection regulations and programs of best management practices.

POLICY TOOLS FOR MANAGING AND PROTECTING WATER QUALITY.

The most common way to advance the protection and enhancement of water quality is through the establishment of standards. This is usually done legislatively and must almost always be done on a national basis. Where the responsibility for managing and maintaining water quality is left to states or provinces or local areas there is a strong tendency for them to compete with each other in the interest of promoting economic growth by creating the laxest possible standards.

Different types of standards can be employed in specifying water quality goals and desired levels of treatment or abatement.

There are four general categories of standards.

Ambient Standards. Ambient standards specify the desired levels of physical, chemical and biological characteristics in water or other receiving media. The specification of an ambient standard is simply a statement of water quality objectives. Specification of ambient standards does not by itself result in achievement of the goals. Rather the standard must be achieved by other means such as the specification and enforcement of discharge standards, pollution fines or other pricing mechanisms all of which can be applied both individually and collectively.

Discharge Standards. Discharge standards express the biological, chemical and physical (and in some cases the quantities) characteristics of waters and other materials that may be discharged to surface waters or other receiving body. The stipulation and enforcement of discharge standards is one way of achieving ambient standards. Discharge standards are effective with point source pollutants where the discharge point can be identified and monitored. They are usually ineffective in controlling non-point sources pollution because of difficulties in identifying the location where the standard can be applied and enforced.

Technology Based Standards. Technology based standards specify the types of technology and related operational considerations needed to achieve an ambient standard. They specify what treatment or treatment technology must be applied to the waste stream before it is discharged. Such standards are usually established based on effectiveness and cost considerations. A familiar example is the requirement for primary, secondary or advanced levels of wastewater treatment.

Input Standards. Input standards specify the quantity and quality of specific inputs used in the production process. Their purpose is to affect the quality and quantity of the residuals that are subsequently generated and discharged into the environment. These have been proposed as a means of dealing with non-point source pollutants but do not have a substantial record of use and/or effectiveness. They are in use to regulate other types of pollutants in some economically advanced countries particularly where they are relatively straightforward and inexpensive to enforce.

Other Methods of Managing Water Quality. While the practices of establishing, implementing and enforcing water quality standards are the most widely used techniques for managing water quality at the source from around the world other options are available. One is the use of prices or taxes on discharges. This technique is based on the Polluter Pays Principle in which the liability of water pollution is clearly vested with the agent who discharges polluting substances. The basic notion is that a discharger must pay a price or a tax on each unit discharged. This scheme provides an incentive to reduce pollution to the point where it is cheaper to pay the tax than to treat or otherwise dispose the wastes in question.

Another form of pricing is to issue tradable discharge permits. The manager decides what amount of pollution is the maximum that should be tolerated. Permits in that amount are then issued to potential dischargers who have the option either of using the permit to avoid the tax or selling them to another discharger and paying the tax themselves. The price of the permits is then established as a consequence of the trade that follows in which buyers are willing to pay for permits at any cost that is lower than the cheapest alternative for treating or reducing the waste and sellers are willing to accept any price that is greater than the cost of the most expensive alternative for treating or reducing the waste. One advantage of schemes of tradable discharge permits is that they automatically lead to the least cost means of achieving the level of water quality that they are intended to achieve.

As previously noted, the management of non-point source pollutants presents a special challenge, and this is particularly true for the successful management of ground water quality.

Best Management Practices. Enforceable programs of best management practices have been shown effective in managing and protecting ground water quality. Such programs specify allowable levels of fertilizer and pesticide, erosion protection regimes and other land use and agricultural practices which lead to minimization or elimination of non-point sources of groundwater contamination. These requirements generally depend for effectiveness on the cooperation of the landowners overlying the aquifer in question They require cooperation from overlying ground water users who must agree on the regulations and also agree on enforcement of those regulations. In general, these programs have worked well in areas where groundwater is either the only available sources of water supply or where users are dependent upon it for a large proportion of use. Examples of success with such programs are found in agricultural areas and, to a lesser extent, in urban situations in the U.S. They appear to be the best available tool for managing non-point sources, especially in agriculture.

Improved management of water resources will require the application of water science as a basis for planning and execution. In many countries a good beginning has been made with the development of programs of integrated watershed management. Much remains to be done, however, and it will be important to develop multidimensional strategies to effectively address the multitude of sources of water quality degradation. Most countries have or are in the process of developing institutions dedicated to improving and maintaining the quality of water. Legal frameworks to govern water quality regulation and control have been established in many countries. Basin-wide governing committees are another frequent institutional tool for protection and regulation. The fact that water quality has many of the features of public good means that such institutions are necessary but that they inevitably confront economic and other pressures which often lead to institutional failure. For the future, water quality institutions will need the capacity to keep up with environmental change due to changes in climate and to address the problems of regulating emerging contaminants. If the water resources of the Americas are to be adequately protected now and, in the future, it will be essential to develop governance arrangements that facilitate rational use of all resources and emphasizes their relationship with each other. The use of science and the development of additional science will be crucial in making these arrangements effective.

CHAPTER V
CONCLUSIONS

It is now vitally important to turn more attention to water quality which is strongly also affecting the availability of water. The growing transformations in human activity undergoing the Americas, such as population growth, urbanization, industrializations and continuing shifts in land use and territorial development, have made the needs for innovation and better management of water quality even more urgent.

The conclusions of this abridged volume on water quality in the Americas can be stated as follows:

1. Only rarely will it be optimal to insist on **no pollution at all or on cleaning up all pollution**. This is because the costs and benefits of pollution control and clean-up should be balanced so that net benefits are maximized.

2. Pollution policies should acknowledge that waste disposal sinks are interrelated and high standards for one sink imply lower standard(s) for the others.

3. Measures of prevention are most important in developing policies and governance.

4. Eutrophication of surface waters is a widespread phenomenon throughout the Americas. It is becoming even more serious due to the artificial enrichment of plant nutrients in receiving waters. The results include the unwanted release of toxins, reductions in dissolved oxygen, and explosive growth of unwanted species that drastically interrupt aquatic biodiversity and the configuration of food webs in aquatic environments.

5. Chemical Contamination of aquatic environments have grown sharply as agriculture and industry have grown throughout the Americas. The diversity of contaminating chemicals has also grown as new pesticides and fertilizers have been developed. The problem is further complicated by the constant appearance of new and emerging chemicals, such as antibiotics, hormones and more in the environment. Toxic mine drainage often results in the release of metallic and other compounds that degrade the quality of both surface and ground waters. Natural contaminants arising from geological formations pose hazards for potable water supplies and need to be identified promptly. Frequently, clean-up of chemical contaminants in the environment is more costly than preventing the contamination to begin with.

6. Biological and other Non-Chemical Contaminants have special impacts both on aquatic ecosystems and water sources for consumption and other uses.

Invasive species are becoming more prominent in many countries and need to be controlled due to their sometimes-drastic effects on the natural habitats of aquatic organisms. They can modify water quality and ecological systems of very large waterbodies such as the entire Great Lakes system of North America.

The continuing massive deforestation caused by land clearing for agriculture and timber harvest in both temperate and especially in tropical zones causes accelerated *sedimentation* rates in waterbodies and the destruction of natural landscapes that intensify erosion. It is urgent to develop multiple efforts for reforestation and to protect areas undergoing natural reforestation. This is particularly true in key areas of watersheds such as recharge and riparian zones.

The advance in technologies for the purification of water in the last decades has greatly improved the control of *microbial contamination*. Still there are problems in urban areas where the continuity of access is not guaranteed. Larger problems of such contamination are especially obvious in rural and peri urban areas where water sources are not protected and infrastructure for purification of water for consumption is not present. Certain pathogenic bacteria, virus and parasites are still not controlled by the present purification technologies.

Treatment of wastewaters throughout Latin America is still one of the main problems in securing water quality in the Americas. Urban treatment plants sometimes are dysfunctional and lack maintenance bringing in contaminated effluents into surface receiving waterbodies. In most countries of Latin America, rural areas have an absence or lack of treatment plants for wastewaters.

Most countries in the hemisphere lack adequate monitoring programs to detect microbial contamination which is fundamentally important to control water quality. Improper disposal of *solid wastes* is a negative influence on water quality throughout Latin-American.

The lack of well functioning sanitary landfills leads to continuing contamination of ground and surface waters from leachates. Specialized treatment for hazardous wastes from different sources is absent in many regions and countries.

7. Groundwater. Protecting the quality of ground water is becoming a more urgent necessity in most countries of the Americas because effective management is either inadequate or absent. Existing management is more the exception than the rule. The majority of groundwater contamination is caused by diffuse pollution from agriculture, mining, inadequate treatment of wastewaters, natural contamination in specific geological substrates, seawater intrusion in coastal areas and more, which makes its regulation more difficult. With accelerating climate change and the possible decline of traditional water supplies, development of effective groundwater management policies is now a high priority.

8. Health. The need to protect humans from waterborne disease is of course the main priority for water management directed to the specific sources destined for human consumption. This demands control and regulation of all types of contaminants from chemical to biological. Most urban areas have improved coverage leaving rural and peri urban areas with needs for future steps to improve coverage. There is also a necessity to upgrade infrastructure for purification and treatment of wastewaters to deal with the present risks taking into consideration emerging contaminants. The need for introduction of improved monitoring programs adapted to national and regional water quality information should be emphasized.

9. Impacts from **Global Climate Change** on water resources have been observed throughout the hemisphere and pose extra challenges for future water management. These challenges must be addressed if water sources, and water qualities are to remain secure. Threats to water quality run from climate impacts including increases in the frequency of extreme events, droughts and floods, which can bring about the release of contaminants affecting different uses to increasing temperatures which cause more frequent algal blooms due to eutrophication processes in surface waters. Increasing aridity makes it even more necessary to prioritize the protection of existing water sources and their quality.

10. Water Quality Governance and Policy Development are the key to improving management of water resources in the future as reductions in water quality mean a decrease in the supply of water. There are difficult challenges in securing water quality governance due to the need for good functioning collective institutional structures to protect water quality and the lack of monitoring in most countries needed to identify specific problems; the difficulty in identifying the exact source of the problem due to non-point sources of contamination adds to the complexity of regulation. Policy tools such as setting standards are required to determine if water quality goals are being met. Best management practices in agriculture and in urban areas are key to bringing about improvements to water quality. The introduction of integral management of watersheds is also essential as these programs develop strategies from a multidimensional approach to confront multiple sources of contamination and problems which affect water quality. It is important to emphasize the need for the the development and application of water sciences to develop effective management programs of water quality.

Water management established in legal institutional frameworks has made important contributions to water governance but has had limitations in making progress in an effective way to improve the management of water quality; in some instances, they have been slow in taking into consideration environmental changes and emerging contaminants affecting water quality. To preserve the existing water resources in the Americas it is essential to develop governance that takes into account the rational use of all resources and their relationship with each other.

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