15 Evaluation of the Pollution of Hydrological River Basins: Priorities and Needs

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15.1 Introduction[1]

The pollution of the environment, particularly that of water and its relation to the population's health, is one of the most important water-related problems to be solved both in Mexico and globally (UN-WWAP, 2003). Assessment of pollution is therefore an obligatory step in solving any problem related to health and environmental risks.

International organizations have developed threshold values for contaminants in environmental compartments by observing the effects of particular compounds or chemical species in biological tests (Aidarov et al., 2002). These values are not comprehensive since they may vary seasonally, geographically, due to climate differences, and as a result of the hydrochemical, hydrobiological, and hydrological characteristics of the water bodies.

Traditionally, evaluation of water pollution is done locally (Troldborg et al., 2008) – for a particular place or site – without quantifying the contamination in the entire watershed. In contrast, if we take the hydrological river basin as the scale of the assessment, it becomes possible to improve the conditions of the rivers and to control the main sources of each type of contaminant (Meays et al., 2006).

The hydrological river basin is the geographic area where the hydrological cycle takes place. This area is delimited by the drainage divide, a topographical division inside which precipitation falls and drains into a stream or river. The *United States Geological Survey* (USGS, 2008) defines the hydrological cycle as the movement of the Earth's water. More specifically, it is the natural and repeated circulation of water in all its phases (liquid, gaseous, and solid) between the atmosphere and the Earth. Several phenomena occur between the hydrological cycle and the river basin, which determine the relation between the two and are conditioned by the geomorphologic characteristics of the river basin (Aparicio, 2001). Since the hydrological river basin is delimited by specific natural geographic conditions, which in turn determine the fate of contaminants discharged into it, it is also the basic unit for the analysis and formulation of solutions to water pollution problems.

Mexican water policy has established the hydrological river basin as the basic unit for water management, and it has allocated water for human consumption as a priority over other functions and uses of water (CONAGUA, 2008a). Water for human consumption must fulfil the quality standards indicated by official norms and ecological criteria (SEMARNAT, 2004). These guidelines include chemical contaminants categorized as *Toxic, Persistent, and Bioaccumulable Substances* (TPBS).

The *North American Commission for Environmental Cooperation* (NACEC) (a subsidiary of the *North American Free Trade Agreement* [NAFTA]) has adapted the following criteria to classify TPBS (NACEC, 2005):

- *toxicity*: adverse effect on human or environmental health;
- *persistence*: half-lives exceeding six months for soil and water and exceeding more than one year for sediments;
- *bioaccumulation* or *bioconcentration* factors larger than 5,000.

Previously, some TPBS were used to fight vector-borne infectious diseases and other plagues without knowledge of the secondary and environmental effects they may have caused. Currently, the effects of TPBS on human and environmental health are becoming better known (Fernández-Bremauntz et al., 2004).

World-wide actions to control the use and emissions of TPBS have focused on the most widely used and most dangerous substances, known as the *Persist-*

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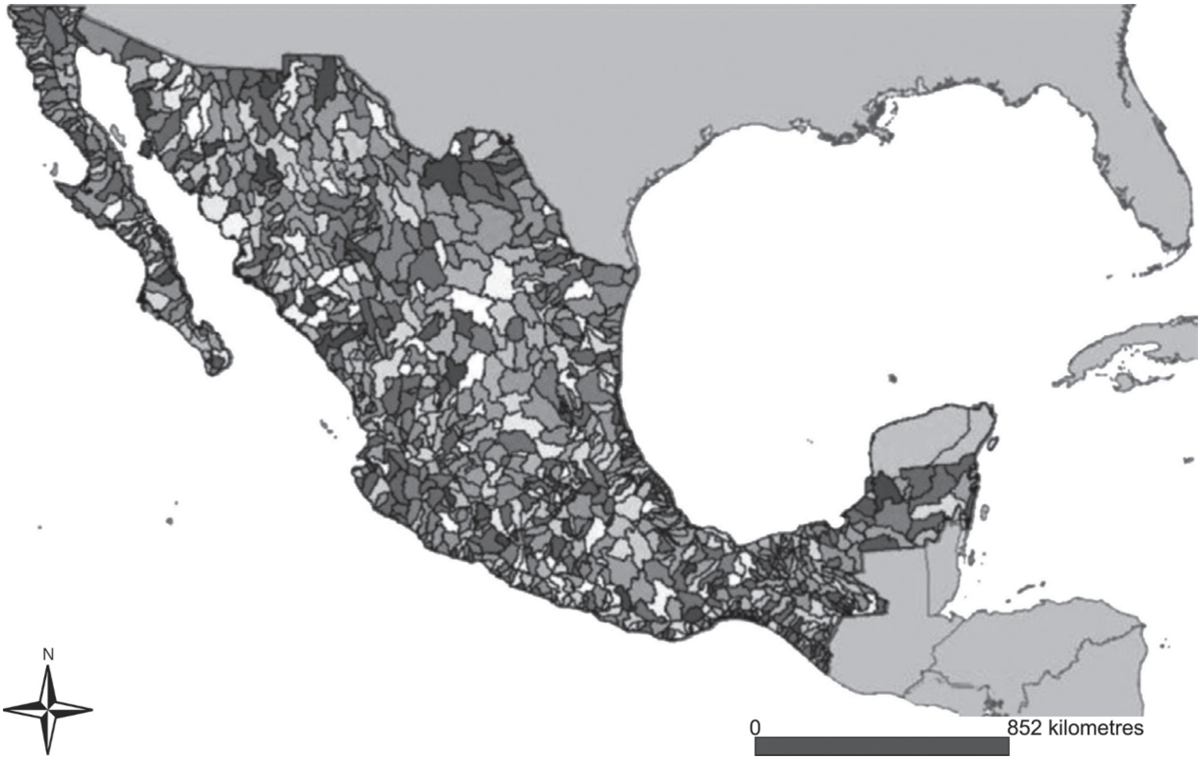
Figure 15.1: Delimitation of the Mexican hydrological basins. **Source:** CONAGUA (2009).



ent Organic Pollutants (POPs). With its incorporation into the Stockholm Convention, Mexico adopted a series of commitments that include research, development, and monitoring of TPBS in general and POPs in particular (Fernández-Bremauntz et al., 2004). Nevertheless, the long-term monitoring of TPBS has not yet been carried out in hydrological basins.

15.2 Objective

The objective of this chapter is to demonstrate the importance of the hydrological river basin as a reference unit for the decision-making process and for the solution of problems of TPBS pollution, and to define and exemplify actions to be included in such an assessment.

15.3 Water Management in Mexico

In Mexico, the hydrological river basin constitutes the basic unit of integrated water management. The 1,471 hydrological river basins (figure 15.1) are located in 13 hydrological-administrative regions (CONAGUA, 2008b). According to the National Law of Water (SEMARNAT, 2004; SARH, 1994), the *National Water Commission* (CONAGUA) is the highest authority over environmental water issues in Mexico. This commission is also the federal authority in charge of the prevention and control of water pollution.

Mexican water policy has adopted these priorities (CONAGUA, 2008a):

- to have sufficient water of suitable quality;
- to recognize the strategic value of water;
- to use water efficiently;
- to protect water bodies; and
- to guarantee sustainable development and environmental conservation.

In synthesis, the priority is to provide water of good quality to the population without causing risks to the ecosystems.

15.4 Methodology

To evaluate and solve pollution problems in hydrological river basins, the following actions should be included:

- creating inventories of pollutant sources;
- sampling and analysing environmental samples;
- evaluating the contamination; and
- modelling.

15.5 Creating Inventories of Pollutant Sources

An inventory of pollutant emissions in hydrological river basins consists of determining the amounts of polluting agents that are released from all types of sources in a given time period. Generally speaking, a water-polluting agent can be defined as any substance released into the hydrosphere which alters its natural composition and which produces adverse effects on humans, animals, vegetation or materials. Water pollution may be the result of a complex mixture of emissions from numerous sources, including industries, urban and domestic sources, soils, and run-off from livestock and agricultural activities.

The purpose of emissions inventories may vary according to specific needs and circumstances. For example, the objective for a single discharge is significantly different from an inventory of emissions for a whole hydrological river basin. The inventory of one discharge can be used to determine if it fulfils specific regulations, whereas the inventory of discharges in a hydrological river basin may sustain water quality programmes and may evaluate the possible environmental impact of multiple contaminant emissions.

Despite the differences between the two approaches, all types of inventories share the following objectives:

- identifying the categories of contaminant sources as well as the location and contribution of each;
- estimating the impacts on water quality through field studies and use of models;
- detecting temporal changes in emission levels;
- increasing efficiencies of methods, programmes, and procedures for water quality control;
- determining the technical specifications for control of wastewater discharges;
- adapting future planning, management, detection, and authorization to protect water from pollution; and
- reviewing the fulfilment of the established limits and guidelines.

To carry out discharge inventories in hydrological river basins, all emission sources should be integrated, including both point and diffuse sources. The methods used to collect and analyse data for these types of sources of pollutants are different. The point sources are those facilities, manufacturers, or activities that discharge in a specific location. Within this category are the majority of the industries, domestic discharges, and collected municipal discharges with and without treatment.

The diffuse sources of contaminants are more dispersed in the hydrological river basin, and they are studied collectively since the measured contaminants do not necessarily correspond to a single source. To ensure that the contaminant inventory is complete and to make the right decisions to solve pollution problems, it is important to identify and include diffuse contaminant sources. This category includes soil erosion, cattle farming, agricultural drainage, sediments as secondary sources of pollution, and contaminants originating from atmospheric transport and deposition. The latter may originate from sources located long distances from the hydrological river basin.

15.5.1 Sampling and Analysing Environmental Samples

Contaminant-monitoring programmes can be classified in two categories. The first type is for control of specific sources or contaminants and is intended for the monitoring of discharges. The second type is for control of the receiving water bodies and of the aquatic life that is exposed to contamination (Hansen et al., 2006).

In Mexico, long-term TPBS monitoring programmes do not exist. Consequently, there are no formal inventories or evaluations of exposures and of consequent risks. Existing monitoring programmes of non-TPBS substances include the *National Monitoring Network* (RNM) carried out since 1973 by CONAGUA, a programme which monitors the quality of surface and groundwater in the Mexican hydrological river basins. Its main objective is to characterize water physically, chemically, and bacteriologically, in order to define regulations and treatment systems for wastewater discharges and for water supplies. In 2007 the RNM included 1,014 monitoring sites (table 15.1). The Primary Network is a permanent component of the RNM aimed at generating long-term information that describes long-term changes in Mexico's most important water bodies. The secondary network is a component more flexible in time and space which monitors the shorter-term impacts of specific pollution sources in aquatic environments. This network supports regulations and pollution control. Results from special studies or case studies carried out by CONAGUA may also be included in the RNM.

Automatic networks of atmospheric monitoring are established in the main urban areas of the country, which provide information about standard atmos-

Figure 15.2: North America and MDN Sites. Blue symbols: active sites; white symbols: inactive sites. **Source:** NADP (2009).

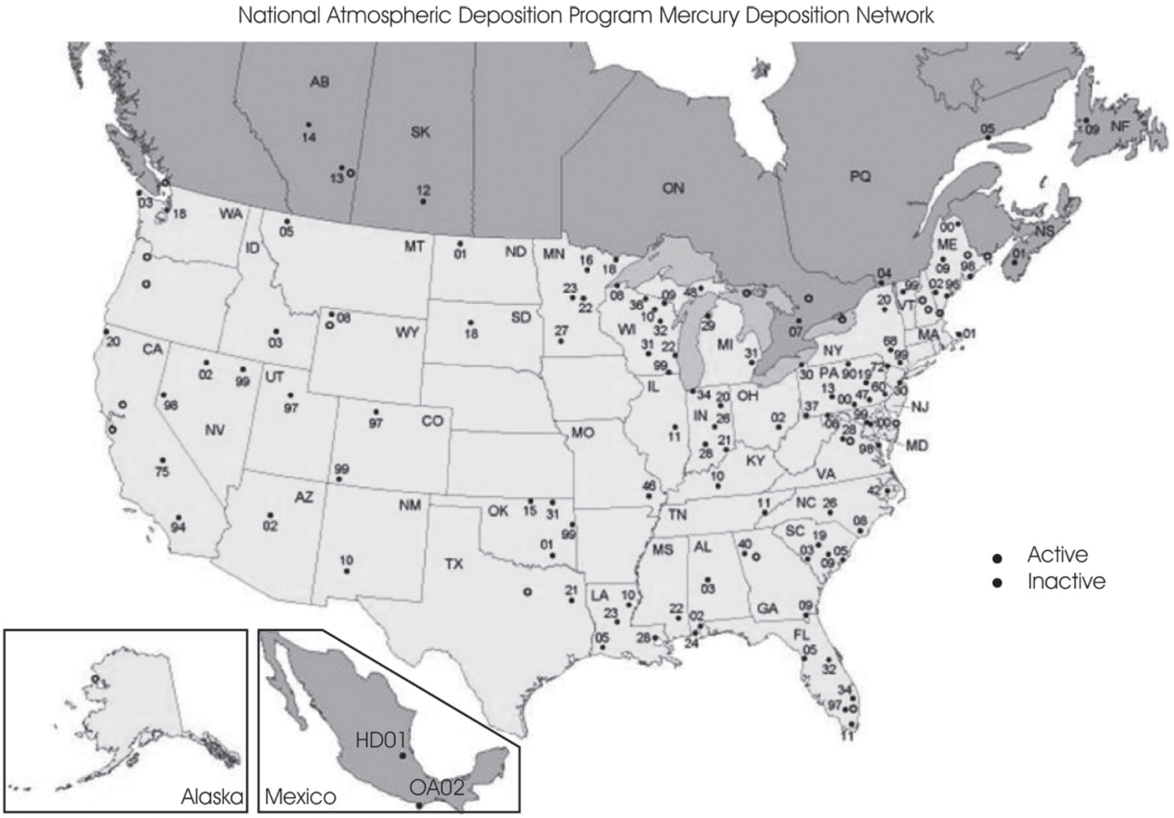


Table 15.1: Distribution of RNM Monitoring Sites. **Source:** CONAGUA (2008b).

Water Body	Primary Network	Secondary Network	Special Studies	Groundwater Reference Network
Surface water	207	241	81	89
Ground-water	130	25	123	
Coastal water	52	19	47	
Total	389	285	251	89

pheric contaminants (CO, SO_2, NO_x, O_3, PM_{10}, Pb, and HC).

None of these monitoring programmes incorporates routine measurements of TPBS. However, universities, research institutes, and centres for technological development carry out TPBS sampling and evaluation projects in environmental media and human tissue, financed by different Mexican government organizations like Mexican Petroleum (PEMEX), CONAGUA, state governments, and the *National Science and Technology Foundation (*CONACYT), as well as by private companies, international agencies like NACEC, and the World Bank. Nevertheless, these studies have specific objectives which often do not coincide and hence they fail to work towards the common goal of evaluating long-term trends in pollution. As a result, it has been impossible to determine changes in the state of the environment and to generate the information necessary for the creation of environmental policies to reduce or eliminate the risks related to TPBS exposure.

An exception to this is the *Mercury Deposition Network* (MDN), which operated two sites in Mexico from 2003 to 2006. MDN is coordinated through the USA's *National Atmospheric Deposition Program* (NADP), and it studies and quantifies the atmospheric fate of mercury and its deposition. MDN collects weekly samples for analysis of the deposition of mercury and methyl mercury in humid precipitation (rain and snow). Recent evidence suggests that the humid deposition of mercury from the atmosphere constitutes the main entrance of this metal into several ecosystems, rural as well as remote, that do not receive direct urban or industrial drainage (NADP, 2009). In 2003, through collaboration between the *Mexican Institute of Water Technology* (IMTA) and NACEC, MDN extended the monitoring area to include two sites in Mexico: HD01 in Huejutla, Hidalgo and OA02 in Puerto Angel, Oaxaca (figure 15.2). Both sites operated until 2006 (NADP, 2009).

Thousands of chemical substances, including TPBS, are produced and used annually worldwide (NACEC, 2005). Analytical methods for evaluating most of these do not exist. Also, due to budgetary limitations in the monitoring programmes, it has been necessary to focus only on those substances which are of major concern. Hansen et al. (2006) developed a methodology for NACEC to define high-priority TPBS to be included in a national programme of monitoring and assessment. This methodology consists of selecting certain TPBS which allow for an instant implementation of such a programme without the immediate need to change existing regulations and infrastructure.

These authors (Hansen et al., 2006) compiled information available on the internet on studies and monitoring of TPBS in Mexico and identified 1,056 studies carried out by 80 different Mexican institutions, mainly on metals and pesticides and, to a smaller extent, on *polyaromatic hydrocarbons* (PAHs), *polychlorinated biphenyls* (PCB), and *dioxins and furans* (D&F). Table 15.2 presents the study media, the types of PBTS, and the main institutions.

Official norms and criteria were analysed for different environmental media as well as the existence of infrastructure for chemical analyses of TPBS and the responsibilities for their monitoring and control (Hansen et al., 2006). Table 15.3 presents the proposed list of 17 individual TPBS or groups of TPBS for immediate implementation. It can be observed that 8 of the 12 Stockholm Convention POPs (Fernández-Bremauntz et al., 2004) are incorporated in this list. It is important to indicate that the proposed TPBS in table 15.3 should be considered an 'open list' that can be extended or reduced according to the needs and requirements of environmental investigations and human health risks. It is also worthwhile mentioning that these recommendations have been formulated for the implementation of an environmental monitoring and assessment programme and not for research or operational programmes aimed at controlling discharges.

To establish priority environmental media for monitoring TPBS, Hansen et al. (2006) identified those of main concern according to environmental policies and international commitments. They distinguished between monitoring aimed at protecting human health and at environmental protection.

The identified priority environmental matrix and their ranking for both monitoring objectives are presented in table 15.4. According to these rankings, monitoring of TPBS for the protection of human

Table 15.2: Compilation of Studies of TPBS in Mexico. **Source:** Hansen et al. (2006).

Medium	Number of Case Studies	Main TPBS	Main Institutions
Air	81	Metals, PAH	UNAM CENICA-INE INSP UAM CINVESTAV IMTA
Surface water	141	Metals, pesticides	IMTA UNAM UAS CIAD UABC
Groundwater and water for human consumption	33	Pesticides, metals	IMTA UNAM UANL IPN UAA
Sediments	93	Metals, pesticides	IMTA UNAM UAM IPN UABC
Soils and other solids	138	Metals, pesticides, PAHs	UNAM IMTA CP UANL INE
Biota	257	Metals, pesticides, PAHs, PCBs	UNAM CINVESTAV IPN CIAD UAS
Food	58	Metals, pesticides, dioxins & furans	UNAM
Human biomonitoring	255	Metals, pesticides	UNAM INSP CINVESTAV UAY UASLP
Total	**1056**		

Table 15.3: Proposed Starting List for Monitoring and Assessment of TPBS in Mexico. **Source:** Hansen et al. (2006).

TPBS	Air	Continental Water	Marine water	Water for human consumption	Sedi-ment	Soil and other solids	Biota	Food	Human biomoni-toring
Aldrin*				X				X	
Cadmium		X		X	X			X	X
Clordane*				X					
Chlorpyrifos								X	
Dieldrin*				X				X	
DDT*				X				X	
Endosulfan		X						X	
Endrin*								X	
Hexachlorocyclohe-xane (alpha, beta)								X	
Heptachloro*/ Heptachloro epoxide				X				X	
Hexachlorobenzene*				X					
Lead		X		X	X			X	X
Lindane		X		X				X	
Mercury		X		X	X		X	X	X
Metoxychlor				X				X	
Pentachlorophenol		X							
PCBs*							X	X	

*Included in the list of 12 POPs

health should focus on the monitoring of food and water for human consumption as pathways for exposure. Both matrices are included in the Mexican regulations and the monitoring of these media could be optimized with little difficulty to include TPBS. Human biomonitoring provides information on the accumulation of TPBS and may help define populations more exposed to these substances. Nevertheless, few reference studies exist, making it difficult to elucidate the outcomes. This same problem appears when atmospheric TPBS results are interpreted. The protection of the environment is also related to human health, and therefore the assessment of monitoring results for surface water, sediments, and biota may provide important information.

15.6 Evaluating the Contamination

The National Water Law (SEMARNAT, 2004) establishes that the quality requirements of water depends on its use and that human consumption has priority over other uses. TPBS are contaminants that may affect water quality since they are slowly degradable in the environment. They may be transported over long distances, and they tend to bioaccumulate. These substances can cause reproductive and growth problems and other harmful effects in humans and biota. It is also suspected that many TPBS are carcinogens. All these effects caused by TPBS are of concern in Mexico and elsewhere (Fernández-Bremauntz et al., 2004).

Table 15.4: Proposed Environmental Matrixes for TPBS Monitoring**. Source:** Hansen et al., 2006).

Ranking	Human health	Environment
1	Food	Sediments
2	Water for human consumption	Surface water
3	Human biomonitoring	Biota
4	Air	Air
5	Surface water	Water for human consumption
6	Sediments	Human biomonitoring
7	Biota	Food

According to Mexican water-related norms and criteria, the following uses of water consider TPBS limits and criteria:

Water for use and human consumption. The Mexican Health Ministry includes in NOM-127-SSA1-1994 (SSA, 2000) "Environmental Health, Water for Use and Human Consumption – Permissible Limits for Quality and Purification of Water" and in NOM-179-SSA1-1998 (SSA, 2001) "Monitoring and Evaluation of Water Quality Control for Use and Human Consumption, Distributed by Public Supply Systems", limits for three TPBS metals (cadmium, mercury and lead) and nine organochlorine pesticides (aldrin, chlordane, dieldrin, DDT, lindane, hexachlorobenzene, heptachlor, heptachlor epoxide, and metoxychlor).

Control and preservation of water bodies. The Mexican Ministry of the Environment includes in NOM-001-SEMARNAT-1996 (SEMARNAP, 1997) "Maximum Permissible Limits in Wastewater Discharges to Waters and National Properties", in NOM-002-SEMARNAT-1996 (SEMARNAP, 1998a) "Maximum Permissible Limits in Wastewater Discharges to Urban or Municipal Sewage Systems" and in NOM-003-SEMARNAT-1997 "Maximum Permissible Limits for Contaminants in Treated Wastewater to be Reused in Services to the Public" (SEMARNAP, 1998b), which establish limits for the same three metals (cadmium, mercury, and lead). Depending on the type of discharge and on the conditions of the receiving body of water, CONAGUA may require the control of additional TPBS in the particular discharge conditions (SEMARNAP, 1998a).

In the ecological water quality criteria CE-CCA-001/89, the *Ministry of Social Development* (SEDUE, 1989) includes contaminant limits for source water for potabilization, water for recreation with direct contact, for irrigation, cattle farming, and aquatic life. Among these, limits on use are established for the three metals mentioned, and for the following 24 individual or groups of organic TPBS: acenaphtene, aldrin, PCB, hexachlorocyclohexane, lindane, bis(2-ethylhexyl)phthalate (DEHP), 4-bromphenyl ether; chlordane, DDT and metabolites, dichlorobenzene, dieldrin, endosulfan, endrin, fluoranthene, heptachlor, hexachlorobenzene, hexachlorobutadiene, hexachloroethane, PAH, metoxichlor, naphthalene, pentachlorophenol, 2,3,7,8 tetrachlorodibenzo-p-dioxin and toxaphene.

The more significant properties of TPBS which allow us to understand their environmental fate are their low solubilities in water, elevated vapour pressures, high octanol-water partition coefficients (K_{ow}), large organic carbon partition coefficients (K_{oc}), and the elevated Henry law constant (K_H).

Due to the high K_{ow} and K_{oc} and low water solubilities, TPBS are mainly associated with organic material and particles suspended in water. The mechanisms of removal of TPBS from the water column include sedimentation and accumulation in sediments. Therefore, it is considered that sediments act as the final destiny of TPBS. Hence, sediments are an excellent environmental matrix for monitoring:

- the historical contamination of TPBS by sampling and analysis of sediment cores; and
- the present TPBS contamination of water bodies through sampling and analysis of recent sediments (those recently accumulated at the water-sediment interface).

The monitoring of sediments is not a common practice in Mexico and it has not yet been decided who is in charge of controlling sediment quality. Considering the responsibilities of CONAGUA as part of the *Mexican Ministry of the Environment* (SEMARNAT) and since the contamination of the sediments is closely related to water quality, the responsibility for monitoring of the sediments should probably belong to CONAGUA.

Due to their physical properties, in most cases the contamination of soils is limited to restricted geographical regions. Soils are thought to act as secondary sources of contaminants for other environmental matrices such as groundwater, surface water, air, and biota. Also, the distribution of TPBS by atmospheric transport and deposition in terrestrial and aquatic environments can relocate contaminants to broader regions. Few decisions have been made to reduce soil contamination, and evaluation has been mostly investigative or aimed at defining remedial actions. Therefore, long-term surveillance programmes for soil quality are non-existent in Mexico.

Soil surveillance monitoring programmes are also non-existent in Mexico. The responsibility for monitoring soil and dangerous goods belongs to the *General Directorate for Integral Management of Materials and Dangerous Activities* (DGGIMAR) of SEMARNAT. DGGIMAR works together with the *Federal Commission for Protection against Sanitary Risks* (COFEPRIS) in the evaluation of risks and with the *Federal Attorney for Environmental Protection* (PROFEPA) in the remediation of contaminated soil.

The monitoring of TPBS in aquatic flora and fauna may have the following objectives:

- biological indicators of water pollution;

- contamination of fish for the protection of consumers (food);
- protection of individual species and ecosystems.

In Mexico, no norms or other regulations exist for aquatic flora and fauna. NOM-004-ZOO-1994 (SAGARPA, 2001) controls the concentration of 14 individual or groups of TPBS (aldrin, dieldrin, cadmium, chloropyrifos, DDT, endosulfan, endrin, hexachlorocyclohexane, heptachlor/heptachlor epoxide, lead, lindane, mercury, metoxychlor, and PCBs in food from animal sources.

15.7 Modelling

There are at least three reasons to construct and use mathematical models to describe the behaviour of contaminants in hydrological river basins (Schnorr, 1996):

- to understand the transport and fate of these substances through information about their movement, reactions, and transformations;
- to determine how aquatic organisms and humans are exposed to contaminants; and
- to predict future scenarios for contaminant discharges and alternatives for the management of contaminant sources.

To select the most appropriate model, specific objectives must be defined for each case. The complexity of the system must be identified and the questions to be answered by means of the model need to be understood. To construct and apply mathematical models in the description of the fate, adverse effects, and migration of contaminants in hydrological river basins, it is necessary to have adequate field data (concentrations and loads), mathematical formulations, velocity constants or equilibrium coefficients, and criteria for the precision required of the model.

Before using a mathematical model to simulate the effects and the fate of contaminants in hydrological river basins, it is necessary to calibrate, verify, and validate the model. The calibration of a model is a statistically acceptable comparison between the results of modelling and measurements in the field. The acceptance criteria for calibration must be defined in advance, and these depend on the use of the results of the model. The verification of the model is a statistically acceptable comparison between the model results and a data set different from the one used for calibration. To verify the model, coefficients and velocity constants should be the same as those obtained in the calibration. The verification of the model guarantees confidence in its predictive results.

Validation is a scientifically acceptable approval of the model that includes and describes the correct formulation of the most important processes involved in the event studied. That a model is validated implies that it works well in different situations and on several sites. Normally, the validation of a model is a gradual process in which its usefulness is defined by comparing its original predictions with periodic field measurements to determine its accuracy. A model is robust if it is useful in numerous applications, under different situations, and in various study areas.

15.7.1 National Priorities from an International Perspective

In this section, the main international treaties are described as well as activities carried out in Mexico for the evaluation and control of TPBS, are reviewed.

15.7.2 The Basel Convention

The Basel Convention for the control of transboundary movements of hazardous wastes was adopted in 1989 in Basel, Switzerland. This treaty strictly regulates the transboundary movements of hazardous wastes and dictates obligations to its parties to assure that dangerous residues are handled and eliminated in environmentally safe ways. The main points of this agreement establish the following (UNEP, 1989; INE, 2003):

- The production of hazardous wastes must be reduced to a minimum.
- Hazardous wastes must be managed and eliminated at the closest possible point to their source of generation.
- Transboundary movements of hazardous wastes must be environmentally safe.

Mexico signed the agreement in 1989 and ratified it in 1991 (INE, 2003). The Basel Convention came into force in 1992.

15.7.3 The Rotterdam Convention

The Rotterdam Convention focuses on the prior informed consent procedure for certain hazardous chemicals and pesticides in international trade. It was adopted in September 1998 in Rotterdam, The Netherlands, as an answer to the growth in the production and commerce of chemical substances during the previous three decades, which had resulted in increased risks associated with the international trade of these chemical substances and pesticides (Fernández-Bremauntz et al., 2004).

In 1980 the *United Nations Environmental Programme* (UNEP) and *the Food and Agriculture Organization* (FAO) developed voluntary programmes for the exchange of information on the commerce of dangerous chemical substances. In 1996 the FAO elaborated and put in practice an International Code of Conduct on the Distribution and Use of Pesticides. This mechanism, denominated Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, is aimed at limiting the exports of dangerous chemical substances and pesticides from developed to developing countries. It was later decided to create an Intergovernmental Committee of Negotiation, which prepared a legally binding instrument that resulted in the Rotterdam Convention. This agreement came into force in 2004 with 73 member states and 128 signatory countries and organizations. The membership is currently made up of 141 countries and organizations. Mexico has neither signed nor ratified this instrument; rather, it has remained an observer (UNEP-FAO, 2009).

15.7.4 The Stockholm Convention

In May 2001, 127 countries adopted a United Nations treaty to ban or reduce the use of of the most toxic substances, considered causes of cancer and congenital defects in humans and animals. The initial 12 POPs subject to this agreement include nine pesticides (aldrin, chlordane, DDT, dieldrin, endrine, heptachloro, hexachlorobenzene, mirex, and toxaphene), one group of industrial products (PCB), and two groups of by-products from various combustion processes (dioxins and furans).

The objective of the Stockholm Convention is to eliminate or restrict the production and use of intentionally produced POPs and to reduce the generation of non-intentional POPs, like dioxins and furans. The Stockholm Convention came into force in May 2004 with 151 signatory countries and 76 member states. Mexico signed the agreement in May 2001 and ratified it in February 2003 (Fernández-Bremauntz et al., 2004).

15.7.5 The North American Commission for Environmental Cooperation

In 1995, Canada, the United States, and Mexico, as member states of the *North American Commission for Environmental Cooperation* (NACEC), created the working group on *Sound Management of Chemicals* (SMOC) in order to establish mechanisms of regional cooperation in the sound management of chemical substances. SMOC considers measures for reduction of sources as well as for prevention and control of pollution, especially for toxic and persistent contaminants.

Six *North American Regional Action Plans* (NARAP) were developed for the management of individual or groups of chemical substances of interest to these three countries: DDT; chlordane; PCB, mercury; lindane; dioxins, furans and hexachlorobenzene. As a result, the requirement to develop research programmes for monitoring and modelling of TPBS was identified, allowing for the detection and evaluation of implications for human health and the environment, with special emphasis on the protection of children's health (Fernández-Bremauntz et al., 2004). In 1999, NACEC established directives to develop a NARAP on *Environmental Monitoring and Assessment* (EMA) that supported the activities of the previous NARAP but also aimed at identifying other TPBS among the other POPs as well as emerging TPBS.

15.7.6 PRONAME and Other Monitoring Programmes

Among the commitments acquired by Mexico as a member of NACEC for the development of EMA was the development of a *National Plan of Environmental Monitoring and Evaluation* (PLANAME) that would identify specific requirements for appropriate decision-making for the characterization and prognosis of the environmental situation in Mexico related to TPBS. In 2005, PLANAME became the *National Program of Environmental Monitoring and Evaluation* (PRONAME), which has as an objective the improvement of the achievement and quality of TPBS monitoring activities in Mexico (INE, 2007).

The strategy for defining and implementing an appropriate monitoring network depends on specific scientific and technical criteria and on the economic situation, as well as on the infrastructure and environmental policies of each country.

Whereas in the USA and Canada the priorities are to develop monitoring strategies for TPBS in various environmental media, through guiding, planning and coordinating existing monitoring programmes (USEPA, 2008), the European Community defined a new strategy of monitoring for the member states that also includes TPBS (European Parliament, 2000).

The questions that should be answered by monitoring and modelling of TPBS in hydrological systems are:

- What are the concentrations of TPBS in water, sediments and aquatic life?
- What are their geographical distributions?
- What are the tendencies in time and distribution of TPBS?
- What are the local, regional, and global sources of TPBS?
- How are they transported?
- Where and how are they accumulated?
- What is their persistence?
- Do they produce chronic effects on humans or on the biota?
- What are the risks of environmental exposure and for human health?
- What are the environmental and health impacts?

To answer these questions for aqueous systems, the hydrological river basin is the recommended study unit, and for Mexico, the infrastructure of the RNM (CONAGUA, 2008b) could function as an excellent base for including TPBS in the list of parameters to be monitored.

15.8 Case Study

With the construction of a dam that will receive water from the Verde and Santiago rivers (figure 15.3) and supply the *Guadalajara urban zone* (ZCG) with 10.5 m^3 s^{-1} for 30 years, over-exploited water supplies such as groundwater and Lake Chapala will be protected. As part of this project, wastewater will be collected and treated throughout the river basins, including wastewater produced in the ZCG. Treated wastewater from ZCG will be returned to the Santiago River downstream from the dam (CEAS, 2006).

Hansen and González Márquez (2010a) reported the results and evaluation of TPBS sampling in water and sediments from the Santiago River. They found that manganese, nickel, copper, and zinc in sediments from the Santiago River showed increasing accumulation with time, while concentrations of arsenic declined, and other metals remained without variation over the past four decades. Concentrations of manganese and nickel in sediments exceeded the Canadian criteria of probable effect on aquatic life (CCME, 2002). In water, the concentrations of nickel were below the ecological criterion for drinking water (SEDUE, 1989).

To evaluate the risk of contaminating water to be stored in the dam, Hansen and González Márquez (2010a) modelled the interaction of contaminants in sediments with overlaying water, simulating varying conditions in the range from aerobic to anaerobic, and sediment re-suspension that may occur during storm flow. The results suggest that manganese concentrations can exceed the limit of the ecological criteria for drinking-water supply (SEDUE, 1989). However, this metal as well as aluminium and iron are easily removed during potabilization of surface water sources (Daniels/Mesner, 2005). The results obtained by Hansen and González Márquez (2010a) suggest that by maintaining sediment accumulation low in the dam, contamination with heavy metals during storm-flow re-suspension would not represent a problem. Nevertheless, if sediments of the current quality are accumulated over time, concentrations of some metals may exceed the ecological criteria for source water for potabilization (SEDUE, 1989) during events of sediment re-suspension.

To prevent the eutrophication (excess of nutrients) of water to be stored in the dam, Corzo Juárez (2009) evaluated the loadings of total nitrogen (N_T), and total phosphorus (P_T) by point sources (industrial discharges and collected municipal wastewater with and without treatment), and by dispersed sources (run-off, agriculture, and livestock) in the river basin of the dam (figure 15.4). He also evaluated the loadings of nickel (Ni).

The loadings of these contaminants by dispersed sources were estimated by calculating run-off taking into account information on precipitation in the region (IMTA, 2005) and the hydrometric information obtained for the rivers (CONAGUA-IMTA, 2007). Average contaminant concentrations in run-off were obtained from Benaman et al. (1996) and Saunders and Maidment (1996). For loadings due to livestock, manure produced was estimated by considering the type of stock (INEGI, 2008) and the concentrations of contaminants according to their weight and purpose of production (Taiganides et al., 1996; Jones/Sutton, 2003). The contaminant loadings from point sources were estimated by analysing the inventory provided by the Jalisco State Water Commission (Óscar Prieto, personal communication) and by means of the con-

Figure 15.3: Study area with sampling points. Source: Hansen et al. (2010).

centrations compiled by Jiménez Cisneros (2001), Hansen et al. (1995) and FAO (1992).

These estimates suggest total annual loadings in the river basin of 132,317 t N_T, 56,309 t of P_T and 0.5 t of Ni. Over 90 per cent of these nutrients correspond to livestock production, especially in the river Verde basin. Considering that secondary municipal wastewater treatment plants typically remove 50 per cent of nutrients (Beavers and Tully, 2005), these would eventually eliminate only 3.4 per cent of N_T and 1.7 per cent of P_T in the whole river basin. Therefore, the collection and treatment of municipal wastewater will not be sufficient to prevent the eutrophication of water. It is therefore necessary to control nutrient loadings, especially from livestock. Control actions may include management of the quantity and quality of animal foodstuff and restricted reuse of manure as agricultural fertilizer.

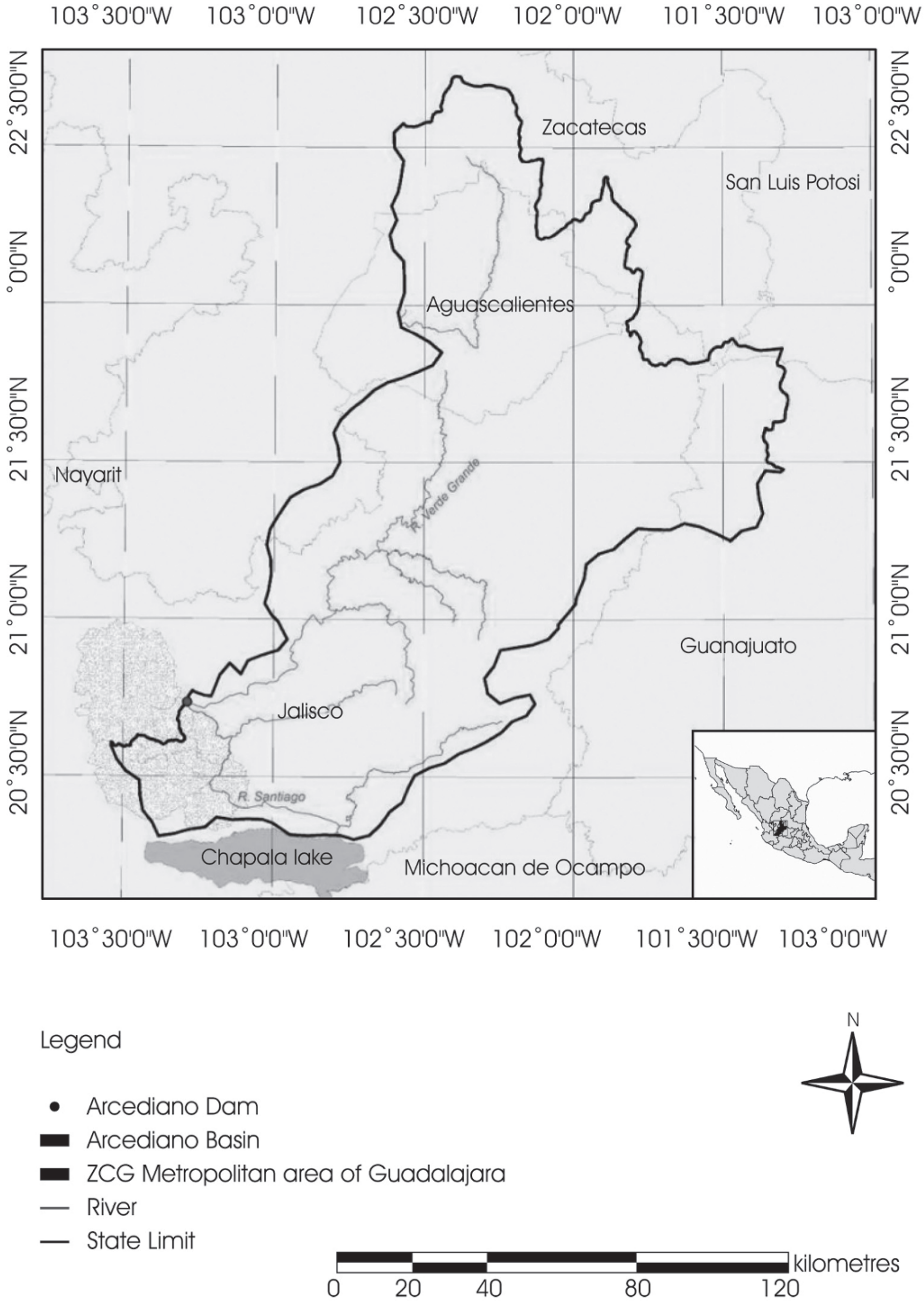
With 70 per cent of the total loadings of Ni, industrial sources in the Santiago River basin are the main sources. It is therefore recommended that an inventory of industrial discharges be made, and pre-treatment systems of wastewater from the industries that discharge this metal be implemented, before incorporating these waters into the municipal sewage treatment plants. This case study demonstrates the importance of considering all the polluting sources in the hydrological river basin, so as to be able to estimate the main source and make the right decisions for solving pollution problems.

15.9 Conclusions

The hydrological river basins provide an adequate reference framework for the development of control strategies for water-related pollution. For the appropriate evaluation of monitoring results of TPBS in hydrological systems, it is recommended that inventories of pollutant sources be made, water and sediments monitored, and contaminant loads evaluated and modelled, as applied to this reference frame.

In order to fulfil international commitments and to protect the health of the environment and the Mexican population, it is essential to implement TPBS

Figure 15.4: Arcediano Dam River Basin**. Source:** Corzo Juárez (2009).



monitoring programmes. Given the lack of TPBS monitoring in Mexico, it is not possible to build on existing programmes. To initiate a programme for the monitoring of TPBS in hydrological river basins, a feasible option is to build on the infrastructure and experience already existing in the RNM (CONAGUA, 2008b).

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