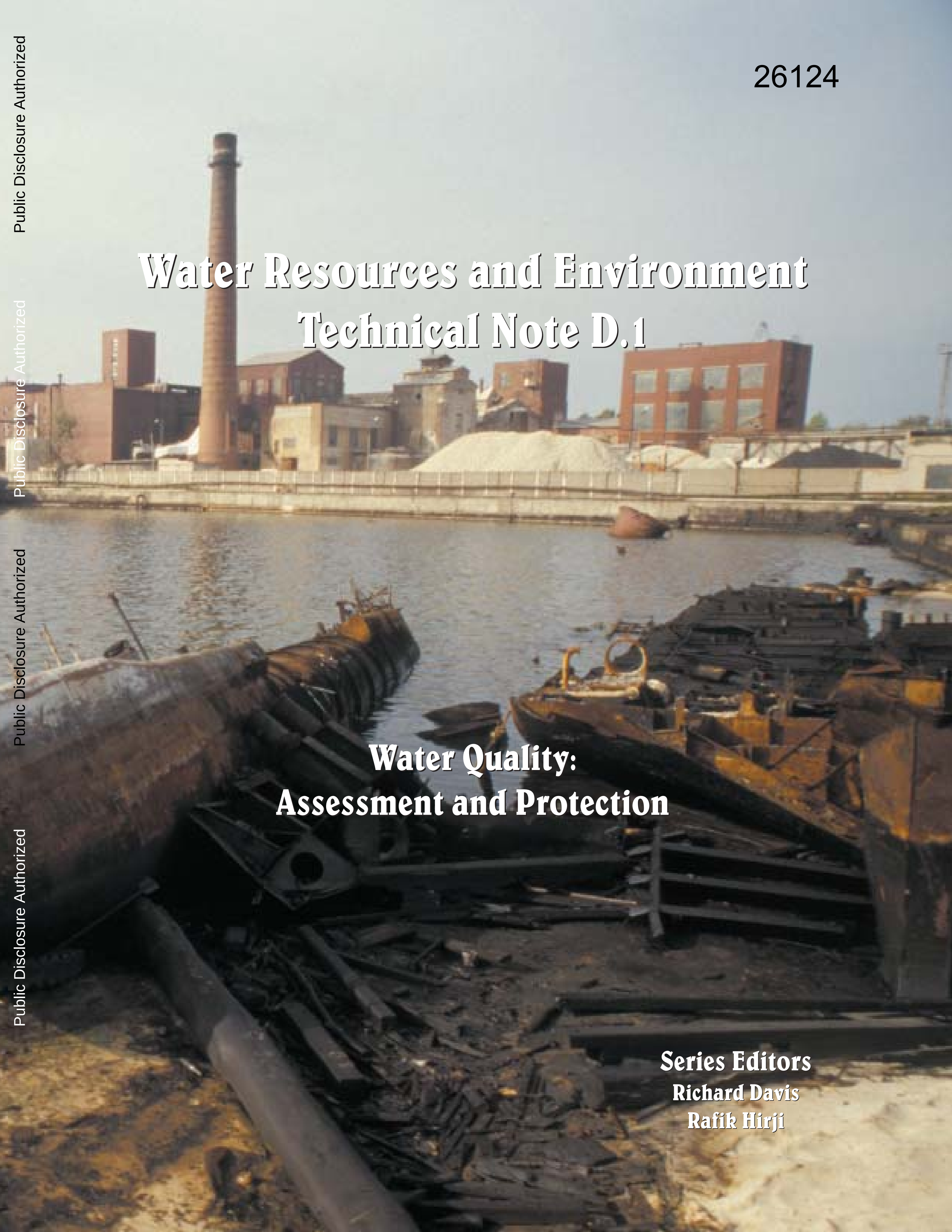

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Water Resources and Environment Technical Note D.1

Water Quality: Assessment and Protection

Series Editors
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Unless otherwise stated,
all dollars = U.S. dollars.
All tons are metric tons.

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Curt Carnemark, World Bank
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This series also is available on the
World Bank website
(www.worldbank.org).

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FOREWORD

The environmentally sustainable development and management of water resources is a critical and complex issue for both rich and poor countries. It is technically challenging and often entails difficult trade-offs among social, economic, and political considerations. Typically, the environment is treated as a marginal issue when it is actually key to sustainable water management.

According to the World Bank's recently approved Water Resources Sector Strategy, "the environment is a special 'water-using sector' in that most environmental concerns are a central part of overall water resources management, and not just a part of a distinct water-using sector" (World Bank 2003: 28). Being integral to overall water resources management, the environment is "voiceless" when other water using sectors have distinct voices. As a consequence, representatives of these other water using sectors need to be fully aware of the importance of environmental aspects of water resources management for the development of their sectoral interests.

For us in the World Bank, water resources management–including the development of surface and groundwater resources for urban, rural, agriculture, energy, mining, and industrial uses, as well as the protection of surface and groundwater sources, pollution control, watershed management, control of water weeds, and restoration of degraded ecosystems such as lakes and wetlands–is an important element of our lending, supporting one of the essential building blocks for sustaining livelihoods and for social and economic development in general. Prior to 1993, environmental considerations of such investments were addressed reactively and primarily through the Bank's safeguard policies. The 1993 Water Resources Management Policy Paper broadened the development focus to include the protection and management of water resources in an environmentally sustainable, socially acceptable, and economically efficient manner as an emerging priority in Bank lending. Many lessons have been learned, and these have contributed to changing attitudes and practices in World Bank operations.

Water resources management is also a critical development issue because of its many links to poverty reduction, including health, agricultural productivity, industrial and energy development, and sustainable growth in downstream communities. But strategies to reduce poverty should not lead to further degradation of water resources or ecological services. Finding a balance between these objectives is an important aspect of the Bank's interest in sustainable development. The 2001 Environment Strategy underscores the linkages among water resources management, environmental sustainability, and poverty, and shows how the 2003 Water Resources Sector Strategy's call for using water as a vehicle for increasing growth and reducing poverty can be carried out in a socially and environmentally responsible manner.

Over the past few decades, many nations have been subjected to the ravages of either droughts or floods. Unsustainable land and water use practices have contributed to the degradation of the water resources base and are undermining the primary investments in water supply, energy and irrigation infrastructure, often also contributing to loss of biodiversity. In response, new policy and institutional reforms are being developed to ensure responsible and sustainable practices are put in place, and new predictive and forecasting techniques are being developed that can help to reduce the impacts and manage the consequences of such events. The Environment and Water Resources Sector Strategies make it clear that water must be treated as a resource that spans multiple uses in a river basin, particularly to maintain sufficient flows of sufficient quality at the appropriate times to offset upstream abstraction and pollution and sustain the downstream social, ecological, and hydrological functions of watersheds and wetlands.

With the support of the Government of the Netherlands, the Environment Department has prepared an initial series of Water Resources and Environment Technical Notes to improve the knowledge base about applying environmental management principles to water resources management. The Technical Note series supports the implementation of the World Bank 1993 Water Resources Management Policy, 2001 Environment Strategy, and 2003 Water Resources Sector Strategy, as well as the implementation of the Bank's safeguard policies. The Notes are also consistent with the Millennium Development Goal objectives related to environmental sustainability of water resources.

The Notes are intended for use by those without specific training in water resources management such as technical specialists, policymakers and managers working on water sector related investments within the Bank; practitioners from bilateral, multilateral, and nongovernmental organizations; and public and private sector specialists interested in environmentally sustainable water resources management. These people may have been trained as environmental, municipal, water resources, irrigation, power, or mining engineers; or as economists, lawyers, sociologists, natural resources specialists, urban planners, environmental planners, or ecologists.

The Notes are in eight categories: environmental issues and lessons; institutional and regulatory issues; environmental flow assessment; water quality management; irrigation and drainage; water conservation (demand management); waterbody management; and selected topics. The series may be expanded in the future to include other relevant categories or topics. Not all topics will be of interest to all specialists. Some will find the review of past environmental practices in the water sector useful for learning and improving their performance; others may find their suggestions for further, more detailed information to be valuable; while still others will find them useful as a reference on emerging topics such as environmental flow assessment, environmental regulations for private water utilities, inter-basin water transfers and climate variability and climate change. The latter topics are likely to be of increasing importance as the World Bank implements its environment and water resources sector strategies and supports the next generation of water resources and environmental policy and institutional reforms.

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Director
Environment Department

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Technical Note D.1 was drafted by Frank Radstake and Albert Tuinhof of Royal Haskoning in Rotterdam, the Netherlands.

This Technical Note was reviewed by David Hanrahan of the World Bank. Helpful comments were provided by Peter Kolsky of the World Bank.

INTRODUCTION

Growing demands for water and increased pollution loads threaten the quality of many lakes, rivers, estuaries and groundwater bodies around the world and pose serious threats to public health, agricultural and industrial production, ecological functions, and biodiversity. Maintenance of water quality is expected to grow in importance in the future. For example, the *World Water Vision* states that deterioration of both surface water and groundwater quality and their impact on ecosystems and biodiversity are central issues for sustainable water resources development and management in the coming decades. There has been insufficient investment in water quality protection for urban and rural needs, according to the report, and there is a critical need to promote integrated water resource management.

The World Bank has been involved in water quality issues for several decades, through investments in sanitation, wastewater treatment and disposal, drainage projects, and, more recently, in some nutrient control programs. Integration of water quality management into water resources management (IWRM) is reflected in the environmental objectives of IWRM in the World Bank's policy paper on Water Resources Management (1993). Water quality aspects are evident in the *Pollution Prevention and Abatement Handbook* (UNIDO, UNEP, World Bank), which provides authoritative and practical advice on implementing water quality programs, including monitoring, use of models, and integrated wastewater management.

Photo by Curt Carnemark, World Bank

Urban Stream, Morocco

Technical Notes D.1 through D.3 deal with water quality. This Note begins with a discussion about general concepts of water quality and integrated water resources management, the objectives of water quality assessment, and the iterative steps in water quality assessment and protection. Thereafter, it discusses water quality standards; information needs and monitoring networks, sampling and analysis of water quality; processing and interpretation of data; water quality management programs; and the general economic, legal, and institutional framework required for water quality management. The Note finishes with some concluding remarks and suggested reading for those seeking more detailed information. Appendixes 1 and 2 provide a glossary of relevant terminology and concepts and a summary of water quality standards. Notes D.2 and D.3 deal with issues specific to municipal wastewater treatment and nonpoint source (diffuse) pollution respectively.

WATER QUALITY AND INTEGRATED WATER RESOURCES MANAGEMENT

WHY IS WATER QUALITY AN ISSUE?

Water resources management has often focused on satisfying increasing demands for water without adequately accounting for the need to protect water quality and preserve ecosystems and biodiversity. Rapidly growing cities and industries, expansion of the mining industry, and the increasing use of chemicals in agriculture have undermined the quality of many rivers, lakes, and aquifers. Poor water quality can create health hazards, as occurs in numerous rivers in the developing world; threaten downstream irrigation areas; reduce industrial capacity through loss of hydropower production and costs arising from removing pollutants; destroy ecosystems; and affect biodiversity. If pollution makes the water unfit for human use, degraded surface and groundwater quality can even add to water shortages in water–scarce regions.

Maintaining good water quality is a growing concern in water resources management around the world. In developing countries, major water quality concerns include fecal contamination from the disposal of untreated or patially treated municipal and domestic wastewater into surface water bodies, and the increased use of pesticides, fertilizers, and herbicides in agriculture. Trace chemicals and pharmaceuticals, which are carcinogens and endocrine disrupters, are now seen as a water quality concern in the industrialized world. Leaks of nuclear waste into surface water and groundwater are a threat, especially in the transition economies of Central and Eastern Europe. As these examples demonstrate, water quality issues depend very much on the context. Thus, chlorination of drinking water can introduce trihalomethanes, which are carcinogenic. While the presence of these compounds is a concern in the developed world, in the developing world the benefits from pathogen removal with chlorination usually far outweigh these risks.

Even though water quality deterioration is often not as visible as water scarcity, its impacts can be just as serious with significant economic consequences. Health hazards, agricultural production losses, and losses of ecological function and biodiversity have long-term effects that are costly to remediate and impose real suffering on those affected. Sediments eroded from watersheds increase turbidity and reduce storage capacity in dams. The UNDP–World Bank Water and Sanitation Program estimates that 6,000 people die every day (or over 2.2 million people a year) from diarrheal diseases; many of these lives could be saved through improved hygiene, sanitation, and water quality. The economic costs associated with water quality degradation are very significant.

KEY WATER QUALITY ISSUES

Both natural processes and human activities can cause deterioration in water quality (Box 1). Table

TABLE 1.
MAJOR POLLUTANT CATEGORIES AND PRINCIPAL SOURCES OF POLLUTANTS

Pollutant Category	Natural Occurrences	Domestic Sewage	Industrial Wastes	Broadacre Agriculture	Intensive Agriculture	Urban Runoff
Oxygen-demanding material		X	X		X	X
Nutrients		X	X	X	X	X
Pathogens	X	X	X		X	X
Suspended solids/sediments	X	X	X	X	X	X
Salts	X		X		X	X
Toxic metals	X		X			X
Toxic organic chemicals			X	X	X	
Heat	X		X			

Modified after: Davis, M.L. and D.A. Cornwell, 1998. *Introduction to Environmental Engineering.* International edition. WCB/McGraw-Hill.

BOX 1.
ARSENIC CONTAMINATION IN BANGLADESH AND RIVER SALINITY IN AUSTRALIA

***Bangladesh*.** The Government of Bangladesh had been active in securing safe drinking water supplies in rural areas by sinking about 4.5 million tube wells. In 1993, arsenic-contaminated water was detected in tube-well water in some southern districts of Bangladesh. Now, arsenic-contaminated wells are found in more than half of Bangladesh's 64 districts.

The arsenic crisis in Bangladesh may be one of the largest poisoning episodes in history. Although only about 1,000 cases of chronic arsenicosis have been reported in Bangladesh, it is estimated that at least 1.2 million people are exposed to arsenic poisoning, and perhaps one-third of the country is potentially exposed.

It has become clear that the arsenic originates in a particular geological deposit in the upper alluvial sediments. Many experts assume that overextraction of groundwater for irrigation caused arsenic to separate from naturally occurring compounds, with consequent water contamination. Arsenic concentrations above the acceptable limit in Bangladesh (0.05 mg/l) have only been found in shallow tube-well water; deep tube-well water does not show arsenic contamination yet. The World Bank is supporting the Bangladesh Arsenic Mitigation/Water Supply Project to provide alternative water supplies and emergency medical relief.

***Australia*.** Over the last 200 years, much of arable Australia's natural vegetation has been cleared and replaced with shallow-rooted annual crops. This has altered the water balance across large areas of the country, causing increasing recharge to groundwater and a concomitant rise in the water table. Many Australian soils contain salts, either from previous marine incursions or from wind-borne deposition, and the rising water tables are bringing this salt to the surface. At least 2.5 million ha (5 percent of the currently cultivated land) are affected by dryland salinity, and 33 percent of rivers are in poor condition. One major city, Adelaide, will fail to meet WHO standards for salt in drinking water 2 days out of 5 within 20 years. Salinity levels are predicted to rise in many major rivers of the Murray-Darling basin, which may endanger their use for irrigation within 20 years.

The state and federal governments have recently agreed to an action plan that includes setting targets for salinity levels in each catchment, developing community-based integrated catchment management plans to meet the targets, building the capacity of communities to implement these plans, improving the governance framework for long-term action, and alerting the public to the long-term risks and options for salinity management.

Sources: Harun-ur-Rashid and Abdul Karim Mridha. 1998. "Arsenic contamination of groundwater in Bangladesh." Proceedings of the 24th WEDC Conference, Islamabad, Pakistan.
Basin Salinity Management Strategy 2001-2015, Murray-Darling Basin Ministerial Council. 2001 *National Action Plan for Salinity and Water Quality.* Canberra: Commonwealth of Australia.

1 summarizes the main sources of pollution from both causes. Water quality concerns also change over time. For example, surface waters may contain a high concentration of sediments in the rainy season because of erosion of catchments, while domestic and industrial waste pollution may be a major concern during the dry season as a result of reduced dilution or restricted microbial activity.

WATER QUALITY AND INTEGRATED WATER RESOURCES MANAGEMENT

Integrated Water Resources Management (IWRM) includes social, economic, and environmental factors in the planning, development, monitoring, and protection of land and water resources. Hence, IWRM is not limited to addressing just physical relationships or water resource characteristics. It also includes water as an integral part of the ecosystem, a finite natural resource, and a social and economic good.

It is essential that water quality issues be addressed within an IWRM framework to properly handle the often-conflicting demands on water resources that arise in many countries, such as competition between irrigation and domestic water supply, increased degradation of water resources, variations in water quality stored behind hydraulic structures (such as dams), and increased cost of treatment. Different economic and environmental uses place different demands on water quality (Table 2).

WATER QUALITY ASSESSMENT AND STANDARDS

WATER QUALITY ASSESSMENT

Water quality assessment is the evaluation of the physical, chemical, and biological condition of a water resource in relation to intended uses. It encompasses monitoring, data evaluation, reporting, and dissemination of the condition of the aquatic environment.

Water quality assesments have a variety of purposes. For example, they can be used to:

- Describe water quality at regional or national scales, including a determination of trends in time and space
- Determine whether or not water quality meets previously defined objectives for designated uses, including public health
- Manage resolution of specific pollution management issues, including post-audit functions
- Determine investment options based on potential benefits from proposed or alternative remediation options
- Provide a comprehensive assesment of river or lake basins and aquifers, especially to determine the relative importance of point- versus nonpoint-source pollution
- Support regional or river and lake basin planning, and groundwater planning, including the development and implementation of national/regional policies.

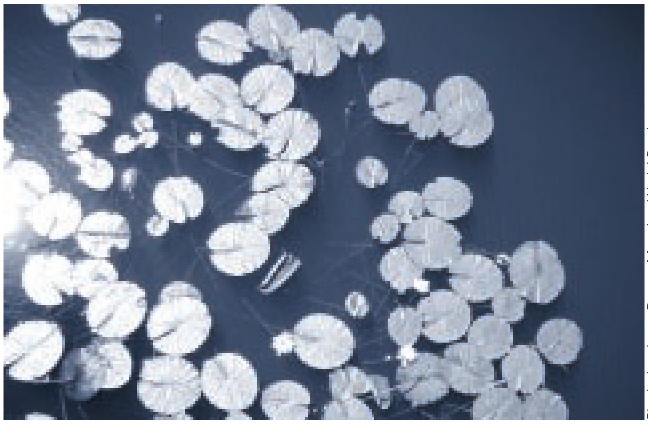

Photo by Jean-Roger Mercier, World Bank

Water lilies, China

- Report on compliance with national or international standards or action plans

WATER QUALITY STANDARDS AND GUIDELINES

The term “standards” usually refers to legally enforceable measures of water quality, while the term “guidelines” is used for nonbinding measures. Unless noted, we will use the term “standards” in this document.

Various water quality standards have been developed to assess the suitability of a water resource for particular uses (Appendix 2 summarizes selected water quality guidelines for drinking water supply, irrigation and livestock supply, and selected guidelines for river water quality and effluent discharges). The WHO drinking water quality standards are a global reference, which are complemented in many countries by local standards. Problems can arise when there are major differences between local standards and international standards. It is also quite common to find incomplete standards. For example, in many countries drinking water quality standards are often well-developed, while standards or even guidelines for irrigation and ecological uses are absent.

Water quality standards and guidelines should be regarded as tools for sound water resources management, rather then an automatic assurance of good water quality. Deviations from standards may be justified for various economic and technical reasons and should be assessed for each specific case. For instance, temporary drinking water quality standards were drafted in Tanzania to permit the use of waters with higher fluoride levels than recommended in WHO standards, since no feasible or cost effective treatment for naturally high fluoride concentrations was available. Standards can be implemented through not only enforcement mechanisms, but also through mechanisms such as financial incentives and public pressure (Box 2).

Box 2.
Pollution control in Indonesia

Indonesia began formal water quality regulation in 1992, establishing maximum allowable volumes and concentrations of BOD and other water pollutants from 14 broadly defined industry sectors such as textiles and wood pulping.

In 1995, the government introduced the Program for Pollution Control, Evaluation and Rating (PROPER PROKASIH). In the program's initial phase, the government decided to focus on compliance with water regulations. Polluters are assigned environmental performance ratings (excellent, good, adequate, poor, or very poor), which are announced to the public. PROPER's ratings are designed to reward good performance and call public attention to polluters who are not in compliance with the regulations. Armed with this information, local communities can negotiate better environmental arrangements with neighboring factories; firms with good performance can advertise their status and claim market rewards for their performance; investors can accurately assess environmental liabilities; and regulators can focus their limited resources on the worst performers. By committing itself to a public disclosure strategy, the environmental agency also reveals its own ability to process information reliably and enforce the existing regulations.

During its first two years of operation, PROPER was effective in moving poor performers toward compliance and motivating some firms to pursue higher ratings. Undeniably, public information is having an important impact on industrial pollution control in Indonesia. The new approach to regulation in Indonesia shows that local communities and market forces can be powerful allies in the struggle against excessive industrial pollution.

Source: Afsah, S., B. Laplante, and D. Wheeler. 1997. *Regulation in the information age: Indonesia Public Information Program for Environmental Management* (www.worldbank.org).

THE MONITORING NETWORK

PURPOSE OF MONITORING

Water quality monitoring can be carried out for different reasons. The UN[1] distinguishes four purposes: (1) basic/reference; (2) effluent control and regulation; (3) protection of functions and uses; and (4) early warning monitoring.

Basic/reference monitoring (Ambient water quality). Government agencies, water boards, and the general public need basic information in order to track changes in water quality and gain a general appreciation of the state of their water resources. This type of monitoring is intended to provide long–term trends in water quality across large areas and can be applied at different scales from national to local. Both groundwater and surface waters should be monitored on a regular basis.

These data underpin indicators of the success of national water resource programs, as well as local efforts to clean up specific water quality problems. However, the lack of a targeted purpose makes reference monitoring susceptible to cutbacks in government support. Table 3 provides typical monitoring design characteristics for the different waterbodies that may need to be monitored.

Monitoring for effluent control and regulation. Regulatory authorities, such as environmental protection agencies, often require industries that are discharging wastes to include water quality monitoring as part of their license conditions. The parameters to be monitored depend on the nature of the wastes and the intended uses of the receiving waters. Discharges from sewage treatment plants will typically be monitored for BOD, fecal coliforms, and nutrients.

This type of monitoring also includes the collection of water quality data on the impact of industries and landfills on groundwater quality. Because

[1] UN/ECE Task Force on Monitoring and Assessment, 1996.

Table 2.
Main water quality characteristics for different water uses

Uses of water resources	Typical issues and concerns	Typical water quality parameters	Examples of international standards/guidelines (See also Appendix 2)
Public water supply (domestic, commercial, industrial, and other public uses)	Expensive treatment Toxic pollution Bacteriological contamination	Turbidity Total dissolved solids Health-related inorganic and organic compounds Microbial quality	WHO guidelines; US Safe Drinking Water Act (SDWA); EU Directive 98/83/EC
Industrial water supply (e.g. food processing)	Expensive treatment Toxic pollution Bacteriological contamination	Largely industry-dependent	World Bank Pollution Prevention and Abatement Handbook (effluent/waste reduction)
Industrial water activities, (e.g. production and cooling)	Expensive treatment	Suspended and dissolved constituents (industry dependent)	World Bank Pollution Prevention and Abatement Handbook (effluent/waste reduction)
Agricultural water supply (irrigation and livestock)	Salinization Bacteriological contamination Toxic pollution	Sodium content Total dissolved solids	FAO guidelines on Water Quality for Agriculture (#29 rev.1)
Navigation (waterways)	Development of sludge banks	Sediments	–
Habitat maintenance (Fish propagation, aquatic and wildlife)	Oxygen depletion Toxic pollution Turbidity	Dissolved oxygen Chlorinated organic compounds	US Clean Water Act; EU Directives 91/271/EEC & 98/15/ EEC (wastewater treatment)
Aquaculture	Oxygen depletion Toxic compounds Temperature	Dissolved oxygen Algal toxins and pesticides Heavy metals and metalloids	Zweig et al 1999
Water contact and recreation (lakes, reservoirs, rivers, estuaries)	Turbid appearance Bacteriological diseases	Turbidity Bacterial quality Toxic compounds	US Clean Water Act; EU Directives 76/160/EEC (bathing water) and 91/271/EEC & 98/15/ EEC (wastewater treatment)

groundwater moves much more slowly than surface water (see Note G.1), it need not be sampled as frequently as surface water.

The industries collecting the data will be required to turn their results over to the regulatory authority for assessment at regular intervals. This approach not only reduces the costs to government, but also has the potential to make the effluent-producing industry more aware of the effectiveness of its pollution abatement measures.

Protection of functions and uses. Places where water is taken from waterbodies–such as lakes, rivers, and aquifers–need to be monitored if the water is intended for sensitive uses such as drinking water, recreation and tourism, fisheries such as aquaculture, and some agricultural uses where water quality could cause economic losses or health problems. This type of monitoring is typically carried out by the water users, such as water supply authorities or aquaculturalists. The parameters to be monitored and the frequency of monitoring depend on the use. For drinking water purposes, for example, they

Table 3.
Basic/reference monitoring: design characteristics for different types of water bodies

Water body	Number and location of sampling sites	Sampling frequency
Main criteria (common to all water bodies)	■ Representativeness of the sample to the water being monitored ■ Accessibility ■ Local knowledge on: • the geohydrology of the system • the uses of the water • the discharges (avoid areas immediately downstream of major effluent)	■ Information goals: information sought, statistical methods employed to obtain the information, statistical characteristic of the water quality "population" being sampled ■ Operational and financial constraints: budget to support travel to sampling sites, distance of samplings from the laboratory, ability of the laboratory to process samples
River	Number of stations ■ Function of the size of the catchment area (e.g. a river basin of 1.000-5.000 km^2 requires about 6 stations) Typical location for each station ■ Zone with complete mixing: single sample taken at mid-stream or some other convenient point ■ Zone without complete mixing: several samples taken at various points in the cross section of the stream, and combined to get a composite sample	■ On average, 12 per year
Lake and reservoir	Number of stations ■ Depends on the possible horizontal mixing ■ The number of stations should be at least, the nearest whole number to the $\log_{10}$ of the area of the lake in km^2 (e.g. a lake of 100 km^2 requires 2 stations) Sampling depth for each station ■ Lake depth > 10m: several samples according to the position and extent of the thermocline ■ Lake depth < 10m: at least 2 samples: – at 1m below the water surface – at 1m above the bottom sediment	For issues other than eutrophication: ■ Minimum: 1 per year at turnover ■ Maximum: 2 per year at turnover, 1 at maximum thermal stratification For eutrophication issues: ■ 12 per year including twice monthly during the summer
Groundwater	Number of stations ■ Network density depends on aquifer characteristics, vulnerability, groundwater exploitation, water use and land use, and population served with groundwater (e.g. 0.02 locations per 100km^2 in Finland, 1.07 per 100 km^2 in the Netherlands) Sample location for each station ■ One sample is usually sufficient to describe the water quality of one aquifer	■ Minimum: 1 per year for large, stable aquifers ■ Maximum: 4 per year for small alluvial aquifers ■ Karst aquifers: same as rivers

Modified after: UNEP/WHO, 1996. Water quality monitoring; R. Ward et al., 1990. Design of water quality monitoring systems.

would include pH, turbidity, salinity, fecal coliforms, and other health measures and, depending on circumstances, other contaminants such as algal toxins and heavy metals. These parameters would normally be obtained once or twice a day.

Early warning monitoring. If an emergency arises from, for example, an accidental spill of contaminants, then government authorities–including local governments–may have to put an early warning monitoring program into place to provide data about the effects of the spill on water quality. Groundwater as well as surface water quality can be affected by such spills. Clearly, the parameters being monitored depend on the nature of the spill. The monitoring sites need to be chosen so that they intercept the spill and can provide information on both its concentration and rate of spread in either ground or surface waters.

MONITORING NETWORK DESIGN

The design of a monitoring network involves three main activities:

- **Selecting the monitoring sites** so they reflect the spatial variability of the water resource. For example, rivers are usually homogeneous vertically, so they can be monitored along their length, but lakes and groundwater aquifers usually need to be monitored in two or three dimensions (Table 3 and Box 3).
- **Selecting the monitoring frequency** to reflect the specific purpose of the monitoring and the flow dynamics of the type of water resource. Thus, surface water flows many times faster than groundwater, while the retention time for a lake or similar waterbody can range from weeks to years. The sampling frequency will need to be sensitive to likely changes in water quality while keeping the costs of sampling and laboratory analysis to a minimum (Table 3 and Box 3).
- **Selecting the parameters** that best demonstrate the water quality issues being managed. The selection of parameters depends on the objective of the monitoring program, the regulatory environment, and technical and financial feasibility considerations. If regulations require a certain percentage reduction in emissions, then the monitoring program will need to include parameters that are relevant to those emissions. The availability of reliable and affordable analytical methods is an important practical consideration when designing a monitoring program for developing countries. Several issues–such as whether analytical facilities are available at a reasonable distance from the monitoring site, or whether the costs of monitoring a specific pollutant are reasonable in relation to the available budget–need to be considered. In many cases, generic water quality indicators (such as

Box 3.
Groundwater quality monitoring in Egypt

The Government of Egypt's Research Institute for Groundwater (RIGW) has established a national groundwater quality monitoring network to (a) measure the long-time quality changes caused by either pollution activities or salt-water intrusion; and (b) describe overall groundwater quality on a national scale. The objective of the monitoring system is to provide decisionmakers with information about the present and future status of groundwater quality.

The principal problem in the design of the monitoring network was to ensure that a relatively small number of monitoring wells would represent large areas. Homogeneous monitoring areas were identified during the design phase. The most important factors expected to influence groundwater quality were believed to be homogeneous within each monitoring area. Priority areas were then selected within these monitoring areas to represent the importance of the aquifers that are present in each area. Additionally, areas that face a salinization risk were added to the priority areas for monitoring.

At present the network consists of 190 observation points, increasing to about 225 points in the coming years. All operating wells have been sampled in the first two sampling rounds. A frequency of one sample per year will be maintained until the natural variation is known.

The RIGW and stakeholders such as water supply companies will set priorities for the different chemical parameters. Once the priorities are assigned, a "critical parameter list" will be established. It contains parameters for which a drinking water limit has been set and that are not easily removed from the groundwater by treatment. A groundwater suitability map for drinking water can be produced when the parameters on this list are compared with monitored groundwater quality.

Source: RIGW/IWACO. 1999 *Environmental Management of Groundwater Resources in Egypt 1994-1999.* Project Achievements.

total dissolved solids (TDS), hardness, electrical conductivity (EC) and sodium adsorption ratio (SAR)) can be successfully used to assess water quality while avoiding the need for expensive laboratory equipment and advanced analytical techniques. Flow parameters–such as discharge, water level, and velocity–may also need to be monitored simultaneously.

While there are some common elements, the parameters needed to monitor the quality of point-source discharges are different from those needed for nonpoint-source pollution. Urban point sources such as effluent treatment plants would normally be monitored for BOD, pathogens, nutrients, and sometimes heavy metals and industrial chemicals. Nonpoint sources such as agriculture would be monitored for sediments, nutrients, and agrochemicals. More detailed information on the particular parameters can be found in Notes D.2 and D.3.

Drinking water quality is not dealt with in this Note. However, this area is the best developed of any water quality monitoring area, because of its great importance. The WHO provides detailed drinking water quality guidelines. (See Appendix 2).

It may be necessary to conduct a preliminary survey to determine the most suitable media, parameters, and sample locations. Such preliminary surveys are often short-term or limited versions of the full-scale assessment.

Water quality monitoring can target different media–chemical, particulate matter, and biota. Transportation processes, chemical and biological transformations, and distribution processes such as absorption and evaporation determine the distribution of various pollutants among different media. Water is by far the most commonly monitored medium. Particulate matter is monitored in lake and river studies because of the number of pollutants that are absorbed on the surface of sediment particles. Biological monitoring techniques are of increasing importance because of their ability to monitor the integrated effects of pollution (Box 4).

Box 4.
Biomonitoring

Biomonitoring uses the responses of aquatic biota (typically invertebrates) as a measure of water quality. This approach has several advantages over chemical monitoring of pollution. First, biomonitoring methods measure effects in which the bioavailability–that is, the ability of organisms to take up chemical compounds–of the compounds of interest is integrated with the concentration of the compounds and their intrinsic toxicity. Secondly, most biological measurements integrate the effects of the pollutants over a large number of individuals and interactive processes. Thirdly, biomonitoring methods are often cheaper, more precise, and more sensitive than chemical analysis in detecting adverse conditions in the environment because the response is accumulative in nature, especially at the higher levels of biological organization. This may lead to a reduction in the number of measurements.

At the same time, it is usually difficult to relate the observed biological effect to specific aspects of pollution. That is, an increase in mortality of the target aquatic organisms will provide a measure of pollution, but it may not be clear what pollutant is responsible or where it is coming from. Pollution abatement policies are written in terms of chemical standards, so biomonitoring will never totally replace chemical analysis. However, in some situations the number of standard chemical analyses can be reduced by allowing bioeffects to trigger chemical analysis (integrated monitoring), thus buying time for more elaborate analytical procedures.

Biomonitoring techniques can be used in several circumstances, including bioaccumulation monitoring for measurements on chemical concentrations in biological material; toxicity monitoring of the responses of individual organisms to toxicants; and ecosystem monitoring of the integrity of ecosystems in the face of environmental perturbations. The latter type of monitoring will include inventories on species composition, density, availability of indicator species, and rates of basic ecological processes.

Source: de Zwart, D. 1995. *Monitoring water quality in the future*. Volume 3: Bio-monitoring

SAMPLING AND ANALYSIS

FIELD SAMPLING

Sampling is the process of taking a representative portion of a water body to determine its quality or properties. Samples are taken either from the water, from suspended matter in the water body, from sediments at the bottom, or from organisms in the water or sediments. Each of these media requires specific sampling techniques. Common physical field measurements for different water bodies are summarized in Table 4.

Table 4.
Relevance of common physical parameters to water quality

Parameter	Device	Information	Rivers	Lakes	Groundwater
Temperature	Thermometer	High values due to thermal pollution (e.g. downstream of power station discharges). Water temperature values are required for the analysis of the other water quality parameters.	■	■	■
pH	pH meter	Controlled by atmospheric CO_2 and/or mineral carbonate buffering. Freshwaters: pH 6.5-7.5 Lower values due to acidic inputs from acid rain, acid mine drainage, illicit acidic discharges Higher values due to algal blooms, illicit alkaline discharges.	■	■	■
Electric conductivity	EC meter	A function of the total dissolved solids at a certain temperature. If sodium chloride is the predominant constituent, the EC indicates whether the water is fresh (EC< 1500mS/cm), brackish (EC between 1.500 and 20.000mS/cm), or salty (EC> 20.000mS/cm).	■	■	■
Dissolved oxygen	Oxygen electrode	Oxygen depletion indicative of presence of oxidizable organic matter (for example, downstream of point source organic waste inputs).	■	■	
Light	Light sensor	Determination of the euphotic depth of a water body, i.e. zone in which photosynthesis occurs.	■	■	
Turbidity	Turbidimeter	Due to biotic and abiotic particles.	■	■	

LABORATORY FACILITIES

The availability of qualified staff and affordable laboratory facilities are often limiting factors in the set-up and implementation of water quality monitoring and, in reality, largely determine the selection of monitoring parameters. The following general rules on analytical and organizational procedures should guide the set-up of laboratory facilities:

- Analytical methods should be well-validated, described, and standardized, and sufficiently elective and robust. Standardization is especially important for parameters–such as COD and BOD–where the results can depend on the analytical method chosen.

- The sensitivity, accuracy, and precision of the measured parameters should correspond with the defined monitoring and/or protection objectives.

Experience shows that it is inefficient to impose rigid legal standards, both for the parameters used for regulation and for the types of analyses that are permitted. Performance-based techniques offer simpler and more cost-effective ways to attain program goals. In these techniques, the method of analysis is not rigidly prescribed, but the outcome must meet predetermined requirements of accuracy and precision. An example of this inefficiency is the requirement in some countries to use an atomic absorption spectrophotometer (AAS) for the analysis of heavy metal concentrations, whereas new techniques using emission spectroscopy would reduce costs by one to two orders of magnitude.

The last section contains information on the costs of standard laboratory procedures.

PROCESSING, INTERPRETATION, AND PRESENTATION OF DATA

DATA PROCESSING

Data should preferably be stored in a computerized database, using a codified system for secondary information (location, station, basin, etc.). Examples of information to be stored include:

- Sampling location: geographical coordinates, name of the water resource, basin or subbasin, state, province, municipality, and type of water resource.
- Sample information: sample location, date and time of sampling, medium sampled, sample matrix, sampling method and/or sampling equipment, depth of sampling, preservation method, field (pre)-treatment, and project identification.
- Measurement results: variable measured, location where the measurement was made (in situ, field, field laboratory, or regular laboratory), analytical method used, and actual result of the measurement, including the units.

Detailed descriptions of possible codes are available from the UNEP/WHO Global Environmental Monitoring System (GEMS). This program, with over 50 participating countries worldwide, provides professional assistance and scientific information on water quality monitoring (Box 5). Use of its recommended codes facilitates the transfer and comparison of water quality data around the world.

Maximum benefit can be obtained from water quality assessments by integrating hydrological and environmental data. Ideally, monitoring data collected by different institutions–such as governmental water and environmental institutions–should be combined in one database.

The resources to buy computerized databases are not available in many parts of the developing world. Whether computerized or manual methods are used, it is important that at least two copies of the analytical results should be kept, with one of them in a secure location.

INTERPRETATION WITH MODELS

Numerous mathematical models covering the transport, transformation, and effects of pollutants are available to help interpret the data. Some, such as mass balance calculations, and simple one-dimensional spreadsheets–for example, for modeling pollutant transport along a river–do not require sophisticated computer technology. Many of these models can be linked with GIS packages to facilitate the presentation and interpretation of the data. Others, such as diffusion/dispersion flow models require more advanced understanding and extensive data sets to be applied and are of less relevance in developing countries.

Box 5.
GEMS Global water quality monitoring program

GEMS/Water was initiated in 1976 by UNEP and WHO with the support of UNESCO and WMO as a global freshwater monitoring network. The primary objectives of the GEMS/Water Program were (a) to monitor the pollution and contamination loads and trends of the world's freshwater resources; and (b) to assist national water quality agencies in improving monitoring and assessment programs.

In August 1990, GEMS/Water entered a new phase. At that point, three long-term objectives were defined:

1. To provide governments, the scientific community, and the public timely access to information on the state of global freshwater, long-term trends in the level of critical freshwater quality indicators, cause-effect relations and impact assessment of observed trends, and policy options for problem containment and solution.
2. To provide assessments on the flux of toxic chemicals, nutrients, and other pollutants from major river basins to the world's oceans and inland seas.
3. To strengthen national water quality monitoring networks in developing countries, including the improvement of analytical capabilities and data quality assurance.

A computerized database (RAISON) containing GEMS/Water information is maintained at the WHO Collaborating Center on Surface and Ground Water Quality at the National Water Research Institute in Canada. Results on the state of global water trends are published on a regular basis. PC-based information systems have been developed for water management purposes. The U.S. Environmental Protection Agency (US/EPA) provides quality control (QC) support to the program. Eight laboratories in 40 countries participate in the QC program in order to ensure data quality.

Sources: http://www.cciw.ca/gems

Each model has a set of assumptions about its proper use. It is essential to understand the limitations and purposes of these models before applying them. While water quality staff can be trained in the use of simple mass balance and spreadsheet models, the more complex models would normally require an experienced modeler.

PRESENTATION AND DISSEMINATION

The presentation and dissemination of water quality assessments can occur on three levels:

- **Presentation of the monitoring data**: for technical audiences it is important to have an insight into the actual data collected. Tables, graphs, and maps are common methods to document monitoring data, normally directly accessible from computerized databases or GIS, although paper records can be used if that is all that is available.
- **Presentation of interpreted data**: a second level consists of the professional interpretation of the data, such as inferring sources of pollution from the observed water quality data, assessing the degree of compliance with standards, and determining trends. This requires the integration of externally collected data, preparation of aggregated data such as quality indexes, and sometimes the application of models.
- **The wider dissemination of the results**: technical analyses must also be tailored to the needs and the level and interest of nontechnical audiences, such as policy/decisionmakers, specific stakeholders, and the general public. Unfortunately, in many cases little attention is paid to this last step, making the outcomes of monitoring unintelligible to general audiences, and clearly reducing the effectiveness of water quality assessment and protection programs.

Although the practical use of GIS and remote sensing data is in most cases limited to visual presentation, these technologies encourage a more systematic approach to information collection and to the analysis of spatial relationships and impacts. Moreover, the possibilities they offer for flexible and effective data presentation make them particularly suitable for nontechnical audiences; for example, as a way to broaden the scope for public participation in investment projects that affect water quality.

THE CHALLENGE IN DEVELOPING COUNTRIES

The above description of a monitoring network, analytical procedures, and data interpretation represents a good practice target. The challenges in most developing nations are far different. It is not uncommon to find that a standard suite of water quality parameters–major ions, nutrients, and microbiology–are being monitored without careful consideration of their management purpose. Wrong parameters are sampled in the wrong places, using the wrong substrates, and at inappropriate frequencies. Laboratory procedures are often poorly controlled and the analytical results are unreliable; laboratory equipment is defective or inoperative because of unaffordable parts or lack of reagents. These difficulties are exacerbated because of limited high-level support arising from the poor linkage between the monitoring programs and management activities. The poor understanding of the potential relevance of the monitoring and assessment programs also compound the problem. The result is that budgets get cut and monitoring programs deteriorate further.

Such situations can be retrieved by following the good practices described above to the extent that they are possible in the developing country. A balance must be struck between reliable water quality monitoring and assessment based on international good practice on the one hand, and what is feasible and sustainable on the other. It is better to invest in a functional, simple design that is robust and reliable than in a technologically advanced design that does not function.

The parameters to be monitored should be selected to illuminate progress toward meeting water quality objectives. Toxicants, especially organic contaminants, might be monitored in rapidly industrializing countries, while microbial parameters are likely to be more relevant in most African, Latin American, and Asian countries. Complicated and sensitive analyses for heavy metals and toxic organic contaminants should be avoided unless the country can genuinely support these analyses in the long run with well-trained staff, clean and maintained facilities, quality control, and full backup services. The most advanced analytical equipment does not need to be used; it is better to use simpler equipment that can be maintained even if the results are less accurate. If advanced analyses need to be carried out for specific purposes, then this work can be contracted out to an accredited outside laboratory.

The water quality standards should be written with these analytical limitations in mind and not simply copied from other international standards. Biological indicators are usually cheaper to use than chemical parameters, require low investments, and match the technical skills of developing countries. They provide a first screening, after which chemical analyses can be employed. Most importantly, the monitoring program needs to be designed around the needs of the water quality management program, and the results need to be communicated to relevant managers in order to keep their support.

In some cases, it is not possible to make existing assessment programs more responsive to program objectives by simply modifying them. In these cases, the water quality assessment program needs to be completely redesigned to make it relevant. Box 6 describes the experience of redesigning the Mexican water quality monitoring network.

Box 6.
Redesigning the Mexican water quality monitoring network

Water quality monitoring in Mexico is carried out by the National Water Commission (CNA). CNA assessed its monitoring programs in the early 1990s and concluded that the information base had no strategic design, had major gaps, was not representative of important areas, was often unreliable, and suffered from out-of-date (or nonexistent) facilities. Programs were not cost-effective and not linked to management requirements for data. Thus, the monitoring network continued to sample water quality parameters that were poorly related to the industrial and agricultural contaminants that were being discharged.

Partly funded by the World Bank, the PROMMA project was instituted to redesign the monitoring and assessment program over the period 1996-2001. The original fixed network of monitoring stations was reduced to a smaller primary network of about 200 stations that would provide long-term descriptive information. A secondary network of stations for regulatory and enforcement purposes was installed for limited periods on highly impacted water bodies, and further stations were planned for investigation purposes and for emergency response purposes. The parameters being monitored were also overhauled, with screening analyses being used to determine which samples merit more costly chemical analyses, indicators being used instead of less informative chemical concentrations, and simplification of parameter schedules. The analytical laboratories were modernized under PROMMA, with a proper quality assurance/quality control program that applied not just to the CNA laboratories but also to the private laboratories that provided analytical services.

A major capacity building program has also been instituted with managerial training, technical training, and the education of users of the services so that they are better able to specify their needs. The institutional structure of CNA has also been simplified: 31 state offices have been reduced to 13 regional offices, and basin councils will be instituted to ensure stakeholder participation. The previous 36 water quality laboratories will be reduced to a national reference laboratory, six regional laboratories, and a number of mobile and fixed laboratories for basic analyses.

Source: Ongley, E.D., and E. B. Ordonez. (1997) "Redesign and modernization of the Mexican water quality monitoring network." *Water International* 22(3): 187-194.

WATER QUALITY MANAGEMENT PROGRAMS

POLICIES AND MANAGEMENT ALTERNATIVES

Water quality monitoring and assessment is closely linked with water quality management. The monitoring program can point out issues needing management intervention; it can also be used to assess the effectiveness of management actions. In principle, waterbodies with acceptable water quality (for the intended beneficial uses) need to be protected from deterioration, while those where water quality is below the required standard will need remedial action.

The UN/ECE Task Force on Monitoring & Assessment (see Further Information) has proposed 10 basic rules for successful water quality assessment and protection:

1. Define the objectives first, and adapt the monitoring program to them, not vice versa (as was often the case for multipurpose monitoring in the past); obtain adequate financial support.
2. Understand the type and nature of the water body (through preliminary surveys), particularly the spatial and temporal variability within the whole water body.
3. Choose the appropriate media for monitoring (water, particulate matter, and biota).
4. Carefully choose the variables, type of samples, sampling frequency, and station location.
5. Select the field, analytical equipment, and laboratory facilities in relation to the objectives, not vice versa.
6. Establish a complete and operational data treatment scheme.

7. Couple the monitoring of the quality of the aquatic environment with the appropriate hydrological monitoring.
8. Regularly check the analytical quality of data through internal and external controls.
9. Give the data to decisionmakers not as a list of variables and their concentrations, but interpreted and assessed by experts with relevant recommendations for management action.
10. Periodically evaluate the program, especially if the environment has changed either naturally or by measures taken in the catchment area.

Box 2 provides an example of policy development and implementation of water quality management in Indonesia.

Water quality management plans should include actions to be undertaken, responsibilities for ensuring implementation, and a time schedule. The actions can include management of both point and nonpoint sources of pollution (Notes D.2 and D.3).

Not all water quality problems need to be tackled. In practice, priorities will need to be established for water quality protection and remediation because of the inevitable limitations on human and financial resources. Both point and nonpoint pollution can cause water quality problems, and management actions can be directed towards either or both types. In many cases, it is simpler to tackle point sources first, since they can be readily identified, quantified, and monitored. However, nonpoint sources—often runoff from agricultural lands—will need to be tackled in many developing countries because they often contribute the largest loads of some important pollutants, particularly nutrients, agrochemicals, and sediments.

FINANCIAL, LEGAL, AND INSTITUTIONAL FRAMEWORK

COST OF WATER PROTECTION PROGRAMS

Table 5 provides estimates of the costs of the main components of a water quality monitoring program based on European experience. Table 6 lists typical laboratory costs for the principal water quality parameters assessed in a water quality monitoring program. Together, the tables provide a basis for estimating the costs of a full water quality assessment program, although these estimates should be modified to reflect local labor costs, information availability, extent of the monitoring network, quality control requirements, and implementation arrangements. In developing countries, the more labor-intensive assessment methods may be more cost-effective than use of costly and high-maintenance equipment. Thus, many monitoring tasks can be carried out locally with relatively low-cost approaches.

Financing water protection programs. Many countries face practical difficulties in putting designed water quality assessment and protection policies into practice. Common constraints include the lack of human resources/institutional capacity, inadequate equipment and poor quality control, impractical water quality and effluent discharge standards, poor financing mechanisms for managing quality and controlling pollution, and lack of enforceability.

A market-oriented approach would partially resolve some efficiency-related constraints. Thus, quality control of laboratory results and investment in training and necessary maintenance can often be improved by putting these services out for tender. However, this would require a shift of thinking in countries where the government has traditionally controlled all aspects of water quality management.

Enforcement costs can be significantly reduced by involving local beneficiaries of improved water quality, delegating responsibilities to those causing and being affected by pollution, and reducing the role of government to that of coordination and enforcement. This not only reduces costs, but creates ownership of water quality assessment and protection programs. Many routine monitoring tasks can be delegated to local levels, with periodic reporting and quality control. For instance, it has been shown that there is less cost to governments and better compliance with environmental standards if industrial effluent monitoring is carried out by the respective industries. The government's role, however, remains critical in setting and enforcing rules, and developing and enforcing national data standards through programs of quality assurance and laboratory accreditation. This means that governments must still retain the capability of checking the monitoring results provided by industries. See Technical Notes D.2 and D.3 for details.

Economic incentives. Economic instruments can be an effective way to reach objectives such as a reduction in pollution discharges (see Note B.2). The "Polluter Pays Principle" is a good yardstick for selecting measures that assign the costs of pollution to the cause of the problem, although in practice a trade-off will have to be reached between the polluter and the beneficiaries of reduced pollution. There are various economic instruments for pollution control.

- **Pollution charges** can work effectively in controlling discharges from facilities that can be monitored at reasonable cost, such as medium and large industrial facilities and municipal sewage treatment plants.
- **Tradable discharge permits** are useful if the number of sources within the water body or basin is large enough to sustain a reasonable level of trade without any one source having a disproportionate influence on the market. This approach is best applied to point sources (rather than diffuse sources) and requires the establishment of a trading system.
- **Increasing the prices** of environmentally damaging inputs to agriculture to better reflect the unpriced costs of environmental damage from excessive use–by removing subsidies, levying

Table 5.
Indicative budget components and costs for water quality monitoring

Budget component	Description	Indicative unit cost (US$)
A. Design of the monitoring network	Consultants, monitoring experts	
B. Implementation of the monitoring network	In the case of groundwater, installation of monitoring wells. As an example, the prices are given for one well in the Netherlands. However these values may increase significantly depending on local conditions (type of soil, number of local contractors, etc.)	50 per meter (depth: 0-10 m) 60–120 per meter (depth 10-100 m)
C. Sample collection (field costs)	• Vehicle for Transportation (car, pick-up) • Field measurement equipment • Working hours (average of 5 samples per day) + transportation.	20,000–50,000 1,500–2,500 90 per sample
D. Data management system	Laptops, database, process software	20,000
E. Laboratory analysis (with quality control)	• Chemical analysis for the most common 20 to 40 parameters. If the analysis includes more specific parameters, like pesticides, this cost may increase significantly. • Biological analysis	200–500 per sample 170–300 per sample
F. Data handling, analysis, and reporting	Working hours. Strongly depend on availability and characteristics of database for storage, calculation, and retrieval.	50–70 per sample

Note: The cost of working hours may vary significantly, depend on local conditions.

TABLE 6.
ANALYTICAL COSTS OF THE MAJOR WATER QUALITY PARAMETERS

Pollutant Category	Parameter	Technique	Investment (in US$)	Labor Time	Operational Costs
Oxygen-demanding material	BOD	Potentiometric	10,000	intermediate	low
Nutrients	Nitrogen and phosphorus	Colorimetric or titrimetric or ion chromatography	30,000 30,000 40,000	low low intermediate	intermediate intermediate intermediate
Suspended solids	TSS	Gravimetric	<100	low	low
Pathogens	Fecal coliforms and fecal streptococcus	Microscopic (sterilization in autoclave)	<5,000	intermediate	low
Salts	Cl^- ions	Specific ion electrode or ion chromatography	< 5,000	low	low
Toxic metals	Heavy metals (e.g. cadmium, mercury)	Atomic absorption spectrophotometry or inductively coupled plasma spectrometry	100,000 150,000	high high	high high
Toxic organic chemicals	Pesticides, herbicides, organic solvents, phenols Oil Acethylcholinesterase inhibiton Organochloride pesticides chlorinated hydrocarbons	Gas chromatography Infra red Colorimetric Coulometric	75,000 15,000 40,000 75,000	intermediate intermediate intermediate intermediate	high low high intermediate

Modified after: UN/ECE task force on monitoring and assessment, 1996.
Note: Investment and operational costs are based on Western European standards. However, these values provide a reference for any certified laboratory in the world.

taxes, or raising prices of agricultural chemicals–may be useful to control nonpoint source pollution.

- **Subsidizing inputs** that improve environmental performance of polluters may be justified, if society would otherwise have to bear the cost of the environmental damage.

LEGAL AND REGULATORY REQUIREMENTS

Effective water quality monitoring and protection programs must be supported by practical and appropriate legislation, regulations, and codes of practice. The legislation, in turn, needs to be supported by a strong government commitment expressed in a national policy statement. Key elements of legislation include clear assignment of institutional roles (including a separation of regulatory from administrative functions); reconciliation with other regulations and legislation; authority to charge for pollution costs through permits; and involvement of diverse stakeholder groups in the management of the water resource. Regulations can include sanitary norms and minimum treatment requirements; assignment of liability; monitoring and surveillance aspects; reporting requirements and data access, water quality standards, interim standards, and exemptions. Note B.2 provides an overview of the regulatory dimensions of water resources management.

INSTITUTIONAL SETTING

Apart from technical and financial constraints, successful implementation of water quality protection and management is dependent on the cooperation of institutions and stakeholders. While water quality standards are often defined on a national scale, pollution control is usually the responsibility of regional or local authorities. Thus, close cooperation among local, regional, and national levels is required for effective implementation of water quality management.

For this reason, it is essential that all stakeholders are encouraged to be actively involved in water quality management. Raising the awareness of people is important because few people will make changes without understanding why change is needed and how the change will affect them. Public consultations and stakeholder workshops can help recognize local practices, discuss the most appropriate approach for implementation, and allow society to participate in integrated water management. Depending on the type, scale, and objectives of the programs, a number of rounds of consultations may need to be organized with stakeholders.

While consultation and cooperative approaches pave the way for successful water quality management, regulatory institutions must retain the ability and willingness to enforce regulations. There are many examples where all the institutional and administrative mechanisms are in place, but water quality remains a serious problem because regulations on point and nonpoint source discharges are simply not enforced.

Internal institutional constraints in large government organizations may hamper the modernization of water quality monitoring and protection. In practice, modernization is impossible if not supported by the senior management. Modernization does not always require additional funds; sometimes, a reassignment of funds and staff is necessary. Without their support, these changes will not occur. Consequently, the benefits of more effective water quality management need to be clearly apparent to the managers of these organizations.

INTERNATIONAL AND TRANSBOUNDARY WATER QUALITY MANAGEMENT

A number of international conventions exist on water quality management in transboundary water basins. The most relevant conventions include the 1991 Convention on Environmental Impact Assessment in a Transboundary Context (in force since 1997), the 1992 Helsinki Convention on the protection and use of Transboundary Watercourses and Lakes (in force since 1996), and a complementary Draft Protocol on Water and Health (signed in 1999). These conventions and protocols have limited practical value beyond defining broad frameworks. Consequently, it is common to prepare more specific multilateral agreements and treaties for transboundary river basin or lake management. However, national interest frequently overrides regional objectives, and international treaties themselves are no guarantee of effective cooperation.

Photo by Yosef Hadar, World Bank

Assistant in laboratory, Thailand

BOX 7.
THE ARAL SEA BASIN

The Aral Sea basin, covering parts of Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan, and a small area in Afghanistan, has been turned into a "disaster zone" due to the diversion of large amounts of inflow from the Syr Darya and Amu Darya Rivers. The Aral Sea lost half its area, and the water flowing into the sea is brackish to saline. As a consequence, there has been widespread unemployment and poverty among the inhabitants of the region.

An international agreement laid a foundation for regional cooperation by establishing an Interstate Commission for Water Coordination (ICWC). In February 1997, a new International Fund for the Aral Sea (IFAS) was proposed as the implementing agency for a GEF Project. Its executive board is made up of five deputy ministers, each of whom represents the respective country portfolio for agriculture, water, and environment. The framework for improving both water quality and quantity is to be supported by improvements in water control infrastructure, flow monitoring, data sharing, studies on water quality, projects to improve management of the upper watersheds, and capacity building for regional institutions.

Preparatory studies toward the design of a water resources management strategy identified water quality as one of eight major issues or themes. The water quality assessment and management study dealt primarily with pollution issues other than salinity, and found that those are not generally of great significance at the regional scale. Recommendations on data collection and information systems have been incorporated into the design of the strategy, while other issues are being dealt with at the national level through National Environmental Plans. Construction projects have been agreed to address problems of the basin environment directly, including large-scale irrigation and drainage improvements, water supply projects for the near-Sea disaster zone, wetland restoration, restoration of the northern Aral Sea, and restoration of some river channels.

Source: World Bank, 1998. Project Document. *Water and Environmental Management Project: Aral Sea Basin Program.* Washington D.C.: World Bank.

BOX 8.
THE LAKE VICTORIA ENVIRONMENTAL MANAGEMENT PROGRAM

Lake Victoria, the largest freshwater body in Africa, is an important economic and natural resource for almost 25 million people. Due to the pressures of population, the introduction of Nile perch, and water hyacinth to the lake, unregulated discharges of pollution, and atmospheric deposition of pollutants, the lake ecosystem has become seriously degraded. Although the Nile perch is an important commercial species, it has eliminated up to 300 of the lake's native fish species, many of which were important sources of protein for the local people. Discharges of untreated sewage, wastewater from industries, deposition of dust and rain on the lake surface, runoff from agriculture and livestock operations, and runoff of sediments due to deforestation have contributed heavy nutrient loads to the lake. The bottom waters of the lake are now seriously depleted of dissolved oxygen and the surface waters are vulnerable to toxic cyanobacterial blooms. Contributing significantly to the problem is the water hyacinth, which first appeared in the lake in 1990 and has multiplied rapidly. This destructive plant forms dense mats, which inhibit navigation and deplete oxygen. It has recently been brought under control.

A Tripartite Agreement (signed August 5, 1994) among the Governments of Kenya, Uganda, and Tanzania formally set in motion the Lake Victoria Environmental Management Project (LVEMP). It is the first phase of a longer-term program to (a) provide the necessary information to improve the management of the lake ecosystem; (b) establish a mechanism for cooperative management by the three countries; and (c) identify and demonstrate practical, self-sustaining remedies, while simultaneously building capacity for ecosystem management.

A major challenge in developing a comprehensive (international) water quality management strategy is the far-reaching economic implications for the member states. Implementing the strategy will not be limited to developing and harmonizing regulations, but also managing pollution by, for example, strengthening enforcement and setting priorities.

Source: Hirji, R., and D. Grey. 1998. "Managing International Waters in Africa: Process and Progress." In World Bank. 1998. *International Watercourses: Enhancing cooperation and managing conflict*. Washington: The World Bank

Implementation can, however, be improved by:

- Fostering regional, subregional, and basin-level dialogue among countries
- Addressing the need for institutional capacity building, information dissemination, and financing
- Promoting national political commitment to integrated water resources management through policy reviews, seminars, and target publications, at all levels.

Boxes 7 and 8 provide illustrative examples of ongoing efforts to improve water quality of international waterbodies through such mechanisms.

CONCLUSION

Water quality deterioration is one of the most important water resource issues of the 21st century. The causes are widespread and arise from nearly every activity within a catchment that directly or indirectly discharges water to lakes, rivers, and coastal areas. The pollutants also are diverse, including pathogens, excess nutrients, sediment loads, and agricultural and industrial chemicals.

This Note has emphasized the need to manage water quality issues as part of an integrated water resources approach because of the close linkages between water quality and quantity issues, as well as rural and urban development. Water quality standards need to be established that recognize the beneficial uses of the various waterbodies. Although based on international standards such as those of WHO, they should be realistic for the resources of the country.

A program to monitor water quality has to be focused on the water quality objectives of the relevant water management program. The monitoring need not be carried out entirely by government agencies–it is common to require point-source dischargers to install a monitoring program and report the results to a regulating agency. Enforcement costs can also be reduced by including stakeholders in water quality in the planning and implementation of management programs, so that they take ownership of polluting activities.

FURTHER INFORMATION

The design of water quality assessment programs is contained in:

Bartram, J. and R. Balance, editors. 1996. *Water Quality Monitoring – A practical guide to the design and implementation of freshwater quality studies and monitoring programmes.* 1st edition. London: Chapman and Hall.

The World Bank Group, in collaboration with the United Nations Industrial Development Organization and United Nations Environment Programme. 1998. *Pollution Prevention and Abatement Handbook*. Washington: World Bank Group.

Chapman, D., editor. 1996. *Water Quality Assessments - A guide to the use of biota, sediments, and water in environmental monitoring*. 2nd edition. London: Chapman and Hall.

United Nations Environment Programme (UNEP) and World Health Organization (WHO). 1988. *Assessment of Freshwater Quality. Report on the results of the UNEP/WHO program on health-related environmental monitoring*. Nairobi: UNEP. (http://www.unep.org)

United Nations/Economic Commission for Europe. Task Force on Monitoring & Assessment. 1996. *Guidelines on Water-Quality Monitoring and Assessment of Transboundary Rivers.* Institute for Inland Water Management and Waste Water Treatment (RIZA), Lelystad, the Netherlands. (This and various other related documents are available at http://www.waterland.net/riza/imac-water/index.html)

Ongley, E.D. 1998. "Modernization of water quality programmes in developing countries: Issues of relevance and cost efficiency." *Water Quality International*, Sept/Oct: 37-42.

Foster, S., R. Hirata, D. Gomes, M. D'Elia and M. Paris. 2002. *Groundwater Quality Protection: A Guide for Water Utilities, Municipal Authorities, and Environment Agencies.* Washington: The World Bank Group.

The UNEP/WHO Global Environmental Monitoring System (GEMS) provides advice and some resources for those undertaking water quality assessment programs. http://www.cciw.ca/gems

International water quality guidelines are described in:

WHO. 1993. *Guidelines for Drinking Water Quality*, 2nd edition & Training pack (2000), both available online at http://www.who.org.

Zweig, R. D., Morton, J. D., and Stewart, M. M. 1999. *Source Water Quality for Aquaculture: A Guide for Assessment.* Washington: The World Bank Group.

The following reference and website provide details on laboratory techniques and laboratory accreditation:

American Public Health Association (APHA). 1995. *Standard methods for the examination of water and wastewater*. 19th edition. Washington, D.C.: APHA.

International Laboratory Accreditation Cooperation (ILAC) (www.ilac.org).

Water quality modeling is described in:

Palmer, M.D. 2001. *Water Quality Modeling: A Guide to Effective Practice.* Washington: The World Bank Group.

APPENDIX 1

GLOSSARY

Abatement – Reducing the degree or intensity of, or eliminating, pollution.

AOX – Chlorinated organic compounds, which may include dioxins, furans, and others, collectively referred to as adsorbable organic halides or AOX.

Biochemical Oxygen Demand (BOD) – A measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. The greater the BOD, the greater the degree of pollution.

Biomonitoring – The use of living organisms to test the suitability of effluents for discharge into receiving waters and to test the quality of such waters downstream from the discharge.

Chemical Oxygen Demand (COD) – A measure of the oxygen required to oxidize all compounds in water, both organic and inorganic. Non-biodegradable and recalcitrant (slowly degrading) compounds, which are not detected by the test for Biochemical Oxygen Demand (BOD), are included in the analysis.

Dissolved Oxygen (DO) – The oxygen freely available in water. Dissolved oxygen is vital to fish and other aquatic life and for the prevention of odors. Traditionally, the level of dissolved oxygen has been accepted as the single most important indicator of a waterbody's ability to support desirable aquatic life. The critical level varies greatly among species, ranging from 4–7.5 mg/l. Secondary and advanced waste treatment are generally designed to protect DO in waste-receiving waters.

Dissolved Solids – Disintegrated organic and inorganic material contained in water.

Eutrophication – The process by which a body of water becomes richer in dissolved nutrients and experiences a seasonal deficiency in dissolved oxygen. Human activities can accelerate the process.

Fecal Coliforms – Microorganisms found in the intestinal tract of humans and animals. Their presence in water indicates fecal pollution and potentially dangerous bacterial contamination by disease-causing microorganisms.

Heavy Metals – Metallic elements with atomic number greater than 20, e.g., mercury and lead. They can damage living things at low concentrations and tend to accumulate in the food chain.

Microorganism – Microscopic organisms such as algae, animals, viruses, bacteria, fungi, and protozoa, some of which cause diseases.

Organic chemicals/compounds – Animal, plant-produced, or manmade substances containing mainly carbon, hydrogen, and oxygen.

Pathogens – Organisms that can cause disease in other organisms or in humans, animals, and plants.

Suspended Solids – Organic and inorganic particles that are carried in flowing water.

Total Dissolved Solids (TDS) – A measure of the amount of material dissolved in water (mostly inorganic salts). Typically aggregates of carbonates, bicarbonates, chlorides, sulfates, phosphates, nitrates, etc. of calcium, magnesium, manganese, sodium, potassium, and other cations which form salts.

Principal sources: WB Pollution Prevention and Abatement Handbook (1998); Water Words Dictionary, Nevada Division of Water Planning (www.state.nv.us/cnr/ndwp/home.htm).

APPENDIX 2

SUMMARY OF SELECTED INTERNATIONAL WATER QUALITY STANDARDS AND GUIDELINES

A. SELECTED DRINKING WATER QUALITY GUIDELINES

WHO categories	Parameter	Units	WHO, 1993	EU, 1998	US-EPA
Bacteriological quality	Total coliforms	Counts/100ml	0	0 (i)	
	Total coliforms	Number of samples/month			5%
Inorganic Chemicals	Arsenic	mg/l	0.01(p)	0.01 (c)	0.05
(of health significance)	Barium	mg/l	0.7		2
	Boron	mg/l	0.5 (p)	1 (c)	
	Cadmium	mg/l	0.003	0.005 (c)	0.005
	Chromium	mg/l	0.05 (p)	0.05 (c)	0.1
	Copper	mg/l	2 (p)	2 (c)	1.3 (r: 1.0)
	Cyanide	mg/l	0.07	0.05 (c)	0.2
	Fluoride	mg/l	1.5	1.5 (c)	4.0 (r: 2.0)
	Lead	mg/l	0.01	0.01 (c)	0.015
	Nickel	mg/l	0.02	0.02 (c)	
	Nitrate - NO_3	mg/l	50	50 (c)	10
	Nitrite - NO_2	mg/l	3	0.5 (c)	1
	Manganese	mg/l	0.5 (p)	0.05 (i)	0.05 (r)
	Mercury	mg/l	0.001	0.001 (c)	0.002
	Selenium	mg/l	0.01	0.01 (c)	0.05
Pesticides	Dieldrin	μg/l	0.03	0.03 (c)	
	Atrazine	μg/l	2	0.03 (c)	3
	DDT	μg/l	2	0.1 (c)	
	Gamma-HCH (Lindane)	μg/l	2	0.1 (c)	0.2
	Permethrin	μg/l	20	0.1 (c)	
	Pesticides total	μg/l		0.5 (c)	
Disinfectants and disinfectant by-products	Chlorine	mg/l	5		
Radioactive constituents	Gross Alpha activity	Bq/litre	0.1		
	Gross Beta activity	Bq/litre	1		
Aesthetic guidelines	Turbidity	NTU	5 (a)		
	Aluminum	mg/l	0.2 (a)	0.2 (i)	0.05 - 0.2 (r)
	Ammonia - N	mg/l	1.5 (a)	0.5 (i)	
	Chloride	mg/l	250 (a)	250 (i)	250 (r)
	Copper	mg/l	1		
	Hydrogen sulfide - H_2S	mg/l	0.05 (a)		
	Iron	mg/l	0.3 (a)	0.2 (i)	0.3 (r)
	Manganese	mg/l	0.1	0.05 (i)	0.05 (r)
	Dissolved Oxygen	mg/l		>5 (i)	
	pH		< 8 (a)	6.5 - 9.5 (i)	6.5 - 8.5 (r)
	Sodium	mg/l	200 (a)	200 (i)	
	Sulfate	mg/l	250 (a)	250 (i)	250 (r)
	Sulfides	mg/l		0.05 (i)	
	Total dissolved solids	mg/l	1000		500 (r)
	Electrical conductivity	μS/cm		2500 (i)	
	Zinc	mg/l	3 (a)		
	Residual chlorine	mg/l	0.6 - 1		

Sources: EU, 1998. Drinking water standards (EU Directive 98/83/EC). (i) Indicator parameter; (c) chemical parameter
US-EPA, 1974. Safe Drinking Water Act (SDWA), plus subsequent amendments. Maximum Contaminant Level (MCL) values (health, enforceable); (r) Secondary Drinking Water Regulations (aesthetically recommended, but nonenforceable)
WHO, 1993. Guidelines for Drinking Water Quality. 2nd edition. (p) Provisional guideline value; (a) aesthetic guideline.

B. Selected irrigation water quality guidelines

Potential irrigation problem	Parameter	Unit	No restriction on use	Slight to moderate restriction on use	Severe restriction on use	Remarks
Salinity (affects crop water availability)	EC_w TDS	µS/cm mg/l	< 700 < 450	700 – 3000 450 – 2000	> 3000 > 2000	
Infiltration (affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)	EC_w	µS/cm	> 700 > 1200 >1900 > 2900 >5000	700 – 200 1200 – 300 1900 – 500 2900 – 1300 5000 – 2900	< 200 < 300 < 500 < 1300 < 2900	SAR: 0 -3 SAR: 3 - 6 SAR: 6 - 12 SAR: 12 - 20 SAR: 20 - 40
Specific Ion Toxicity (affects sensitive crops)	Sodium (Na) Chloride (Cl) Boron (B)	SAR me/l me/l me/l mg/l	< 3 < 3 < 4 < 3 < 0.7	3 – 9 > 3 4 – 10 > 3 0.7 – 3.0	> 9 > 10 > 3.0	Surface irrigation Sprinkler irrigation Surface irrigation Sprinkler irrigation
Miscellaneous effects (affects susceptible crops)	Nitrogen (NO_3-N) Bicarbonate (HCO_3) pH	mg/l me/l	< 5 < 1.5	5 – 30 1.5 – 8.5 Normal range 6.5 - 8.4	> 30 > 8.5	

Source: FAO, 1985 - Water Quality for Agriculture (#29 rev.1).

C. Selected water quality guidelines for Livestock

Parameter	Units	Value	Ratings/indicator
Salinity (Electrical Conductivity)	µS/cm	< 1500 1500 - 5000 5000 - 8000 8000 - 11000 11000 - 16000 > 16000	Excellent Very satisfactory Satisfactory for livestock; unfit for poultry Limited use for livestock, unfit for poultry Very limited use Not recommended
Magnesium (maximum values)	mg/l	< 250 < 400 < 500	Poultry, Swine, Horses, cows (lactating), Ewes with lambs Beef cattle Adult sheep

Sources: FAO, 1986 - Water for animals. Report # AGL/MISC/4/85. FAO, 1985 - Water Quality for Agriculture (#29 rev.1). Values are the limits between None - Slight/moderate - Severe.

D. SELECTED GUIDELINES FOR RIVER WATER QUALITY

Parameter	Units	EU
Microbiological		
Total coliforms	Counts/100ml	500 / 10000
Fecal coliforms	Counts/100ml	100 / 2000
Physico-chemical		
pH		6 – 9
Phenol	mg/l	<0.005 / <0.05

Sources: EU, 1975 – Bathing water quality (EU Directive 76/160/EEC). guide / mandatory values. US-EPA, 1972 – Clean Water Act (CWA), plus subsequent amendments. Recommended values for State regulation.

E. SELECTED EFFLUENT DISCHARGE GUIDELINES

World Bank Categories	Parameter	Units	EU, 1991	WB, 1998
Miscellaneous	pH			6-9
	Biochemical Oxygen Demand - BOD_5	mg/l	25	50
	Chemical Oxygen Demand - COD	mg/l	125	250
	Total suspended solids	mg/l	35–60	50
	Oils and grease	mg/l		10
	Phenol	mg/l		0.5
	Cyanide	mg/l		0.1
	Ammonia - N	mg/l		10
	Total Nitrogen	mg/l	10–15 (s)	
	Total phosphorus	mg/l	1–2 (s)	2
	Residual chlorine	mg/l		0.2
	Total coliforms	MPN/100ml		<400
	Temperature increase	°C		<3
Metals	Arsenic	mg/l		0.1
	Cadmium	mg/l		0.1
	Chromium	mg/l		0.1
	Copper	mg/l		0.5
	Fluoride	mg/l		20
	Iron	mg/l		3.5
	Lead	mg/l		0.1–0.2
	Mercury	mg/l		0.01
	Nickel	mg/l		0.5
	Selenium	mg/l		0.1
	Silver	mg/l		0.5
	Sulfides	mg/l		1
	Zinc	mg/l		2
	Total Toxic metals	mg/l		5–10

Sources: EU, 1991 - Urban Waste Water Treatment (EU Directives 91/271/EEC & 98/15/EEC). (s) for sensitive (eutrophication) areas only; upper limits applies to smaller systems (i.e. 10 000 - 100 000 population equivalents).
WB, 1998 - Pollution Prevention and Abatement Handbook. General Environmental and Manufacturing guidelines