FRESHWATER POLLUTION

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The UNEP/GEMS Environment Library

The Global Environment Monitoring System (GEMS) now has more than a decade of solid achievement behind it. In that time, we have helped make major environmental assessments of such things as the greenhouse problem, the rate of degradation of the world's tropical forests and the numbers of threatened species— including the African elephant—in the world.

As is proper, the results of these assessments have been regularly published as technical documents. Until now, however, they have not been published in a form that can be easily understood by those without technical qualifications in the subjects concerned.

The aim of the UNEP/GEMS Environment Library is to rectify this omission.

This is the sixth volume in the series, and over the coming months and years we plan to publish many more. Only in this way can the result of our environmental assessments become widely known. And only if they are widely known is public opinion likely to become sufficiently vociferous to demand that everything possible be done to halt the deterioration of our environment, and preserve for future generations the possibility to survive and flourish as we have been able to do.

Michael D. Gwynne, Director
Global Environment Monitoring System

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FAO/W. Gartung

The cover shows a child in Kenya drinking from a recently installed supply of clean water. Millions of people world-wide do not have access to clean water, because pollutants are reducing the quality of water available for human use.

Foreword

Mostafa K. Tolba

Humans have been polluting their water supplies since civilization began. But now, because there are many more of us using the same amount of water—and because our demands have increased—problems of scarcity and contamination are becoming severe.

The UNEP/WHO GEMS assessment, *Global Freshwater Quality*, on which this publication is based covers data relating mainly to the period 1974–84. The assessment summarizes the results of GEMS/Water monitoring data, outlines critical freshwater quality issues, proposes policy options and gives examples of control measures. The assessment thus provided the first global picture of the state of much of the world's freshwater resources. Unfortunately, this picture is far from reassuring.

Most large-scale human activities—from mining and industry to farming and forest clearing—affect our water supplies, often leaving people with substandard drinking water. This is especially true in developing countries, where water is rarely treated before consumption, exposing many to the risk of water-borne infection and causing scandalously high rates of infant mortality.

Ground water is contaminated with nitrates from chemically supported agriculture; many lakes and reservoirs are becoming increasingly eutrophied and their ability to support aquatic life is being threatened; rivers carry toxic loads of heavy metals and industrial or domestic waste downstream to towns and, eventually, the sea; and land is going out of production at a frightening rate, poisoned by salt that has been concentrated by inefficient irrigation.

Although reversing the damage done will itself be complicated and expensive, it is important—indeed essential—to minimize further harm. One way is by publicizing the issues. This volume of the UNEP/GEMS Environment Library—like the others in the series—is published to do just that: to inform, in plain language, those who need to know. Making more people more aware of what is happening to their water supplies may be one of the most effective ways of slowing down water pollution.

Mostafa K. Tolba
Executive Director
United Nations Environment Programme

Overview

... many arid and semi-arid parts of the world are already without reliable sources of freshwater.

The amount of water on Earth is constant and cannot be increased or decreased. Of a global total of 1360 million cubic kilometres of water, which cover about 70 percent of the Earth's surface, only three percent is fresh, and of that, less than one percent is available for human use in the form of surface waters such as rivers and lakes. Although there is ample fresh water on Earth to meet present and future demand, it is often not where it is needed. Uneven distribution of ground water, surface water and rainfall means that many arid and semi-arid parts of the world are without reliable sources of fresh water.

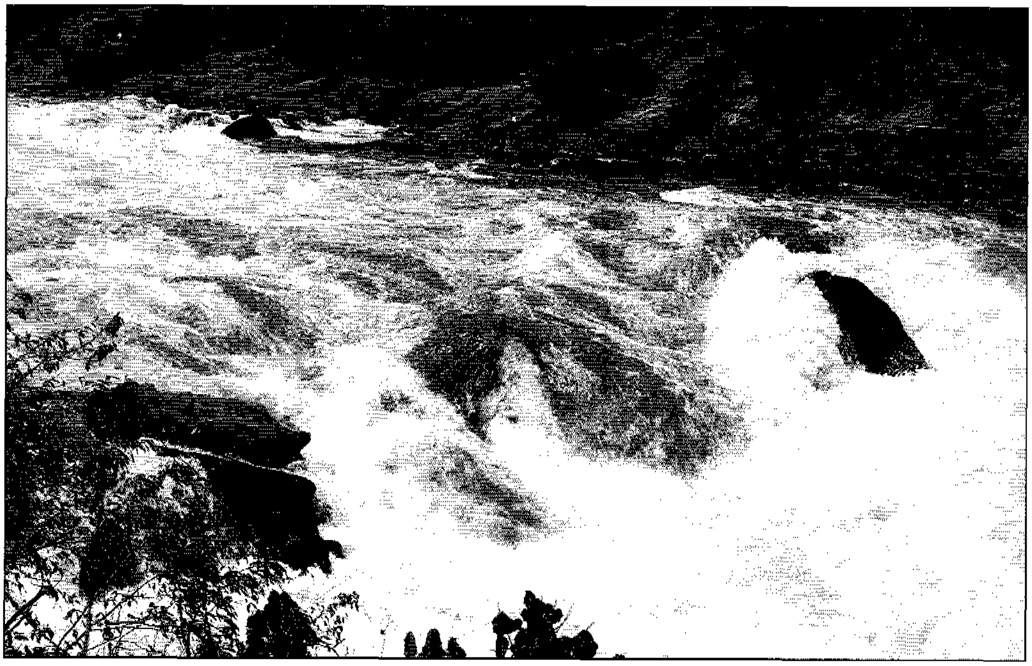
To add to this problem, water is polluted when it is used in industry, agriculture and for domestic purposes, and thus the amount of water of acceptable quality available for human use is reduced still further.

In response to these problems, the Global Environment Monitoring System (GEMS) has, since 1977, been working through the World Health Organization (WHO), UNESCO and the World Meteorological Organization to develop a global water quality monitoring network. This network now includes 344 monitoring stations—240 river stations, 43 lake stations and 61 groundwater stations. More than 50 water variables are monitored, providing information on the suitability of water for human consumption, and for agricultural, commercial and industrial uses. The results of this programme were assessed in 1988, and the broad conclusions of that assessment are summarized in this publication. Further assessments are planned at five-year intervals.

In developing countries untreated water ... causes an estimated 25 000 deaths a day ...

The assessment found that sewage, nutrients, toxic metals, and industrial and agricultural chemicals are the main water pollutants. Of these, the most widespread pollutant is the organic matter present in domestic sewage. In developing countries untreated water is the most commonly-encountered health threat and still causes an estimated 25 000 deaths a day—either because infected water is consumed or because its use leads indirectly to infection from vector-borne diseases such as malaria and bilharzia. Water pollution in these countries has worsened in the 20th century as industrialization and urbanization, accompanied by poor waste treatment practices, have strained water resources and sanitation services.

Monitoring also showed that water pollution is not confined to developing countries. Increasing industrialization and intensive agricultural techniques in developed countries have resulted in a range of pollutants being released into the environment—most



Rapids in Malawi's Upper Shire River. Similar sources of fresh water of adequate quality and quantity—are becoming rare as the remaining water resources are increasingly exploited, industry expands and agricultural chemicals used more intensively.

FAO

of which are eventually transferred into lakes and rivers. European and US rivers were found to contain excessive levels of nutrients which caused a number of major problems including the promotion of algal 'blooms' and the subsequent lowering of oxygen levels in the water that are caused by the decay of algal material. Mining and industry were identified as the major sources of metal contamination of water and other industries contributed to water acidification as a result of the release of nitrogen and sulphur oxides into the atmosphere during fossil fuel burning. Deforestation and the destruction of natural 'filters' such as wetland areas were identified as important causes of increased sediment in water.

Industrial and agricultural pollution controls and environmental protection measures can go a long way towards reducing water pollution. It is hoped that the data presented in the UNEP/WHO assessment will convince the public and decision makers of the urgent need to protect and manage water resources for future generations.

Water pollution ...has worsened in the 20th century as industrialization and urbanization, accompanied by poor waste treatment practices, have strained water resources and sanitation services.

The scientific background

Is there a water shortage?

Many factors ... considerably reduce the annual precipitation reliably available for human use—from a theoretical total of about 40 000 km^3 to about 9000 km^3.

Less than three percent of the Earth's 1360 million cubic kilometres (km^3) of water is fresh; of that, some 29 million km^3 are locked up in snow and ice, some 8 million km^3 are in the form of groundwater, and only about 200 000 km^3 exist as rivers and lakes.

Freshwater is renewed in the hydrological cycle of evaporation and precipitation (*see Figure 1*), most of it rapidly (every year or so) but some of it, such as some groundwater sources, much more slowly (every few thousand years). Typical recycling times are shown in Table 1.

Average annual global rainfall over land is about 110 000 km^3, but 70 000 km^3 are lost through evaporation before reaching the sea. This leaves 40 000 km^3 of run-off—about one-third of total rainfall over land—potentially available for use.

The actual quantity of renewable freshwater on which the human population can draw is in practice considerably smaller. Some of the total precipitation falls on uninhabited areas, such as Antarctica, and is thus of no relevance to human use. Much falls heavily over short periods, and runs off into the sea too quickly to be exploited. In addition, annual variations in rainfall mean that the volume of precipitation that can be guaranteed every year, without fail, is considerably smaller than the annual average.

Table 1 Average renewal cycle times for different freshwater bodies and the ocean vary from a few days to several thousand years.

Average water renewal cycles for different water bodies

permanent snow	9700 years
oceans	2500 years
groundwater	1400 years
lakes	17 years
swamp water	5 years
soil moisture	1 year
streams	16 days
atmospheric moisture	8 days

These factors considerably reduce the annual precipitation reliably available for human use—from a theoretical total of about 40 000 km^3 to about 9000 km^3. Even so, were this precipitation evenly distributed over the globe, there would be plenty for present and future needs. Current annual freshwater consumption is, in round figures, about 4000 km^3—still less than half the available total. This is the equivalent of 800 m^3 per person per year for a population of 5000 million.

On this basis, there would seem to be at least sufficient water to meet future growth. But the situation is not that simple. There is more to determining whether supplies are adequate than adding up the world's water resources and dividing the result by the number of people.

For one thing, rainfall is very unevenly distributed. Yearly per capita run-off ranges from about 120 000 m^3 in Canada to only about 70 m^3 in Malta. South America provides about 10 times more per capita run-off than either Asia or Europe, and predictions suggest that, by 2000, there will be even greater imbalances between continents. While per-capita availability in Europe and North America will not change greatly, less water will be available to each Asian, African and Latin American as their populations continue to grow. Water availability is a critical factor in socio-economic development, limiting progress in many areas such as Sahelian Africa and other arid and semi-arid zones.

As a result of shortages water of inferior quality is often used to meet demand. Conversely, the need for clean water makes heavy demands on total resources. For example, it is estimated that some 450 km^3 of wastewater currently enters the world's rivers. Some 6000 km^3 of water is needed to transport this waste away, and dilute it. Cleansing the world's wastes thus requires a volume of water equivalent to two-thirds of total reliable run-off.

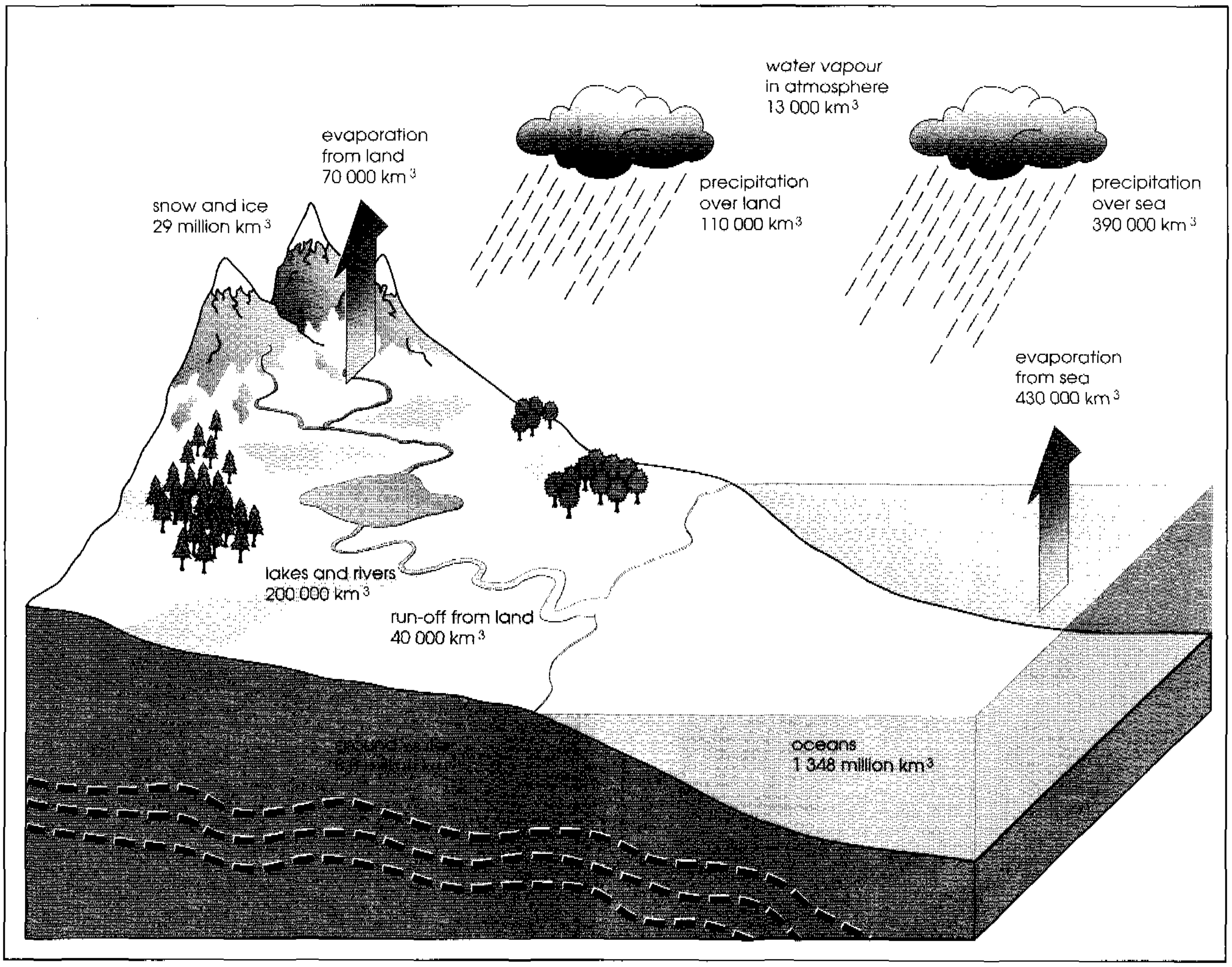


Figure 1 The global hydrological cycle governs the availability of fresh water for human use. The difference between precipitation over land and evaporation is about 40 000 km³—which is the total available run-off from rivers into the sea. Of this, only some 9000 km³ is reliably available over inhabited land, and this is the annual supply on which the human population must depend. The diagram also shows the quantities of freshwater locked up in snow and ice, in groundwater, and stored in lakes and rivers.

Table 2 A 1986 survey by the World Resources Institute found that water availability in 51 out of 100 selected countries was either low or very low.

Per capita water availability in selected countries

category	per capita availability	countries (%)
very low	1000 m^3/year or less	14
low	1000–5000 m^3/year	37
medium	5000–10 000 m^3/year	14
high	10 000 m^3/year and more	35

Inadequate supplies and heavy pollution mean that at least one-fifth of urban dwellers and three-quarters of the rural population in developing countries still lack safe drinking water. The situation is particularly serious in countries with large arid and semi-arid zones and increasing populations, as well as in regions with abundant water resources but large populations.

Agriculture—particularly irrigation—accounts for more than two-thirds of all human water use. The need for irrigation water is strongly correlated with climate. In India, for example, irrigation accounts for 97 percent of all water used.

At present, an estimated 50–80 percent of irrigation water never serves the purpose for which it was intended, either because it percolates down through the soil too quickly or because it runs straight off the field before moistening the soil around plant roots. With predictions that by the year 2000 irrigation demands alone will equal total world-wide water needs in 1980, it is essential to improve irrigation efficiency.

Industrial needs are forecast to grow more slowly. Industry is becoming more water conscious and is beginning to recycle more of the water it uses. In the northern hemisphere, increased recycling in some—mostly industrialized—countries has reduced industrial water demand, despite increased output. Finland, The Netherlands and the United Kingdom, for example, are all using less water in industrial processes as a result.

Municipal wastewater can also be reused for irrigation and by certain industries. Israel is already reusing 30 percent of all wastewater and returning sewage to the land for irrigation and fertilization. By the year 2000, Israel plans to be able to recycle 80 percent of its wastewater.

While not the main concern here, questions of water supply and demand often cannot easily be disentangled from issues of water quality. Because human populations are pressing against the limits of available water supply in many parts of the world, water quality is frequently put at risk.

Agriculture—particularly irrigation—accounts for more than two-thirds of all human water use ... At present, an estimated 50–80 percent of that water never serves the purpose for which it was intended.

Water uses and water quality

Different levels of water purity are required for different types of water use. There are five basic categories of water use: public water supply, mainly destined for human consumption; water used in agriculture; in industry; for recreation; and for fisheries and wildlife. Each category of use has its own quality criteria and methods for assessing suitability. The highest standards of purity are required for drinking water, while, on the other hand, it is acceptable for water used for industrial cooling to be relatively highly polluted.

Public Water Supply

Microbiological indicators are the most important parameters for water intended for domestic use. Several inorganic compounds, such as nitrates, fluorides, arsenic and iodine—which affect health at high concentrations—should also be monitored. So should mercury and lead, which affect the central nervous system; and some organic micropollutants, such as benzene, which are carcinogenic. Salinity, however, is rarely a health hazard; humans do not drink water that is too salty.

Today there are advanced treatment processes available for recycling waste water and even desalinating seawater for public supply. But even the most advanced treatment processes sometimes cannot purify highly polluted water sufficiently to reduce pollution below recommended guidelines. Lack of treatment plants and scarcity of resources in many developing countries means that domestic supplies are often polluted.

Agriculture

Irrigation is by far the largest use of water in arid and semi-arid zones. The most important variable in evaluating water suitability for irrigation is the sodium absorption ratio (SAR) used as a measure of salinity. Prolonged use of irrigation

Existence of water quality guidelines for different water uses

	drinking water	*irrigation water*	*livestock watering*	*fisheries*
microbiological criteria				
coliforms	●			
nematode eggs		●		
particulate matter	●			●
organic pollutants†				●
nitrates	●	●	●	
nitrites			●	●
salinity	*	●	●	●
inorganic micropollutants	●	●	●	●
organic micropollutantsǀ	●			●
pesticides	●			●

* fluoride only

ǀ indicated by dissolved oxygen, BOD and COD

† trace-level concentrations of compounds composed mainly of hydrogen and carbon

Table 3 Different water uses require different forms of control—the table left shows major areas in which recommended safety guidelines exist for different water uses.

water with a high SAR can damage soil structure and crops. Recommended salinity limits differ from crop to crop. Poultry and other livestock can tolerate higher salinity levels than human beings. The effects of trace elements on certain crops must also be considered. Farmers are advised to follow drinking-water guidelines for crops.

Because of the need to reuse treated wastewater for agriculture, WHO has recently recommended guideline levels for intestinal nematode (worm) eggs in irrigation water; these are stringent where edible crops are eaten raw, slightly less so if they are cooked.

Industry

Water is used in industry as a raw material, transport medium, cleansing agent and steam source. It is also used as a coolant (mostly for power stations), a use which demands only low-quality supplies. Industry is increasingly recycling its water. Wastewater and desalinated seawater can be used in many industrial applications.

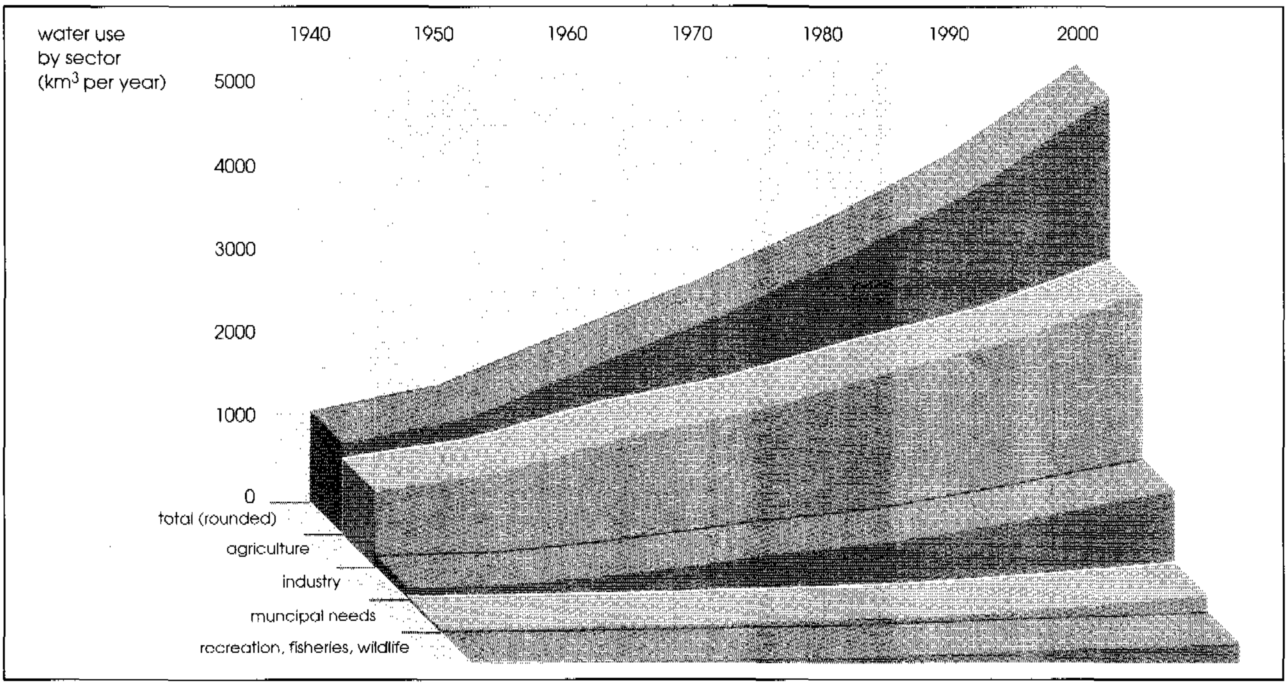
Fisheries and wildlife

It is difficult to establish a single set of guidelines for all contaminants for all freshwater fish, but dissolved oxygen is universally critical to aquatic life. Organic and inorganic micropollutants, such as polynuclear aromatic hydrocarbons (PAHs), and chlorinated organic compounds, such as polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB), can cause tumours, spinal curvatures and other deformities in fish.

Recreation

Despite difficulties of directly correlating particular bacteria in water to illness through water-contact, many countries have set guidelines of 100–1000 faecal coliforms per 100 ml for bathing water.

Figure 2 Water use by demand sector over the period 1940 to the year 2000. Agriculture consumes the lion's share and the importance of industrial demand decreases as industry recycles more and more of its supplies.



The acceleration of pollution

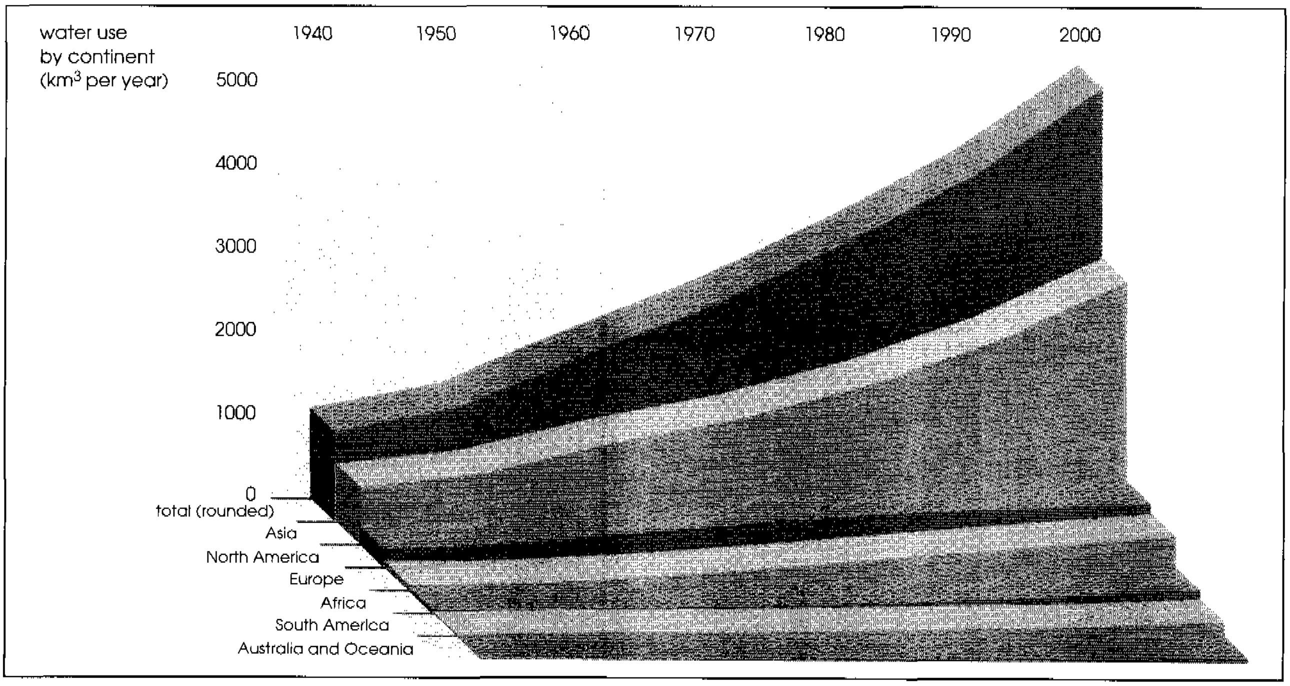
Even in Roman times, heavy metals from mining and pathogens from cities caused serious, though local, water contamination. Since the industrial revolution, water pollution problems have become first regional, then continental, and now global. The major factors associated with the accelerating pace of freshwater pollution are described below.

Urbanization and the consequent increase in population, intensification of agriculture and growth in industries may result in increased freshwater pollution—particularly when coupled with inadequate sewage collection and treatment. Water supplies can be overloaded by organic material, bacteria and nutrients from municipal sewage outlets, factory effluent outlets and stormwater run-off into open drains. Oxygen levels are reduced as these contaminants are broken down, contributing to eutrophication. Bacterial contamination is particularly severe in water-scarce developing countries, where sewage treatment is often inadequate or non-existent. Infants and children particularly lack resistance to such contamination and many die from drinking polluted water.

The problem looks bound to worsen if populations increase—as is predicted—by a factor of five in Africa and three in Latin America before stabilizing. Much of the increased population is likely to live in cities. Cities such as Delhi, São Paulo, Mexico City and Nairobi, which are already major sources of water pollution, are expected to grow up to 50 times larger between 1950 and 2000; and by the year 2000, 75 percent of Latin America's population will be living in urban areas.

Deforestation to clear land for agriculture and urban growth often leads to water contamination. When soil is stripped of its

Figure 3 Water use by continent from 1940 to the year 2000 shows how water use will increase nearly fivefold by the end of the century, putting increasing pressure on the quality of a natural resource with limited availability.



protective vegetative covering, it becomes prone to soil erosion. This, in turn, leads to higher water turbidity as a result of increased amounts of suspended matter, nutrient-leaching and the decreased water-retention capacity of the soil.

Damming rivers to form reservoirs can alter water quality by increasing residence time and evaporation, and by decreasing levels of suspended matter (due to settling). Fewer nutrients are carried downstream and fisheries often suffer.

Destruction of wetlands, besides destroying the habitat of many birds and fish, removes natural filters capable of storing and degrading many pollutants, such as phosphorus and heavy metals. Between 1950 and 1980, the United States destroyed 18 percent of its wetlands, Finland 15 percent and the Federal Republic of Germany 52 percent.

Mining and industrial development doubled between 1965 and 1984, generating much potentially toxic waste, including harmful synthetic organic material. Some of this waste, through leaching of mine tailings, direct effluent, atmospheric transport or other means, made its way into water supplies. The volume of most industrial waste is expected to double by the year 2000, with faster rates of increase in developing countries. It is difficult to monitor industrial pollutants because they are varied and often highly diluted.

Agricultural production increased globally by 19 percent between 1975 and 1984, and doubled in many developing countries over the same period. Annual fertilizer use varies from less than 1 kg/ha in parts of Africa to more than 700 kg/ha in The Netherlands, contributing worrying amounts of nitrates (and phosphates) to water supplies. Though the developed world has the highest levels of fertilizer use at present, developing countries are catching up. In 1980, fertilizer use per hectare in developing countries was 5.5 times less than in developed countries, but by 1986 this figure had dropped to only 2.2. And pesticide use has increased much more than fertilizer use. In Canada, for instance, pesticide sales increased eightfold between 1970 and 1980. Over-irrigation can aggravate the situation by pushing water, with its chemical pollutants, below root level and closer to groundwater.

Primary energy consumption almost doubled between 1965 and 1984, resulting in greatly increased atmospheric emissions of sulphur and nitrogen oxides, the main cause of acid rain. Acidification of fresh water, particularly lakes, is a major concern. Many Scandinavian lakes have become acidified by sulphur emissions from the rest of Europe—thousands of lakes have, in effect, been killed. More important for human health, this process has led to higher levels of metal in water supplies and food chains as trace elements are leached from soil and pipes by acid water. North-east America and northern Europe are already badly affected by acidification; parts of South-east Asia, India and South America are also at risk because of increasing emissions of sulphur and nitrogen oxides.

Accidental water pollution can arise from many sources (such as burst pipes and tanks, major leaks, fires and oil spills) and can cause varying degrees of damage, depending on the quantity, toxicity and persistence of the pollutant, and the size and resilience of the water body. Industrial accidents involving spillages of long-lasting pollutants such as radioactive materials, heavy metals and persistent organic substances have the most serious effects on water quality.

The GEMS assessment

Since 1977, the United Nations Environment Programme (UNEP) and the World Health Organization (WHO) have been collecting data on priority water pollutants from selected water monitoring stations under the Global Environment Monitoring System (GEMS). Today, the GEMS/Water network has 344 stations covering rivers (240), lakes (43) and groundwater (61) world-wide.

One of the objectives of this undertaking is to provide the data from which to evaluate global water quality, paying particular attention to regional differences. Water quality is determined from the measurement of some 50 water quality variables, including:

☐ faecal coliforms;
☐ biochemical oxygen demand;
☐ nitrates and phosphorus;
☐ suspended matter;
☐ heavy metals;
☐ organic micropollutants;
☐ acidity; and
☐ salinity.

Although some stations are located in remote 'backwaters', and are used to establish baseline levels of water quality, most—the impact stations—are near industrial or urban areas, and are specifically sited to measure the impact of human activity on water quality. Preliminary assessments used data collected from 1979 to 1981, and from 1982 to 1984 and compared them with recommended guidelines (where they exist) for the relevant pollutant. More recent data have been fed directly into the GEMS/Water global databank at the Canada Centre for Inland Waters in Burlington, Ontario. In 1988, data from these sources were used as the basis of a GEMS assessment of the state of the world's fresh water. Not all major lakes and rivers are included in the GEMS network (particularly those in Africa, the Soviet

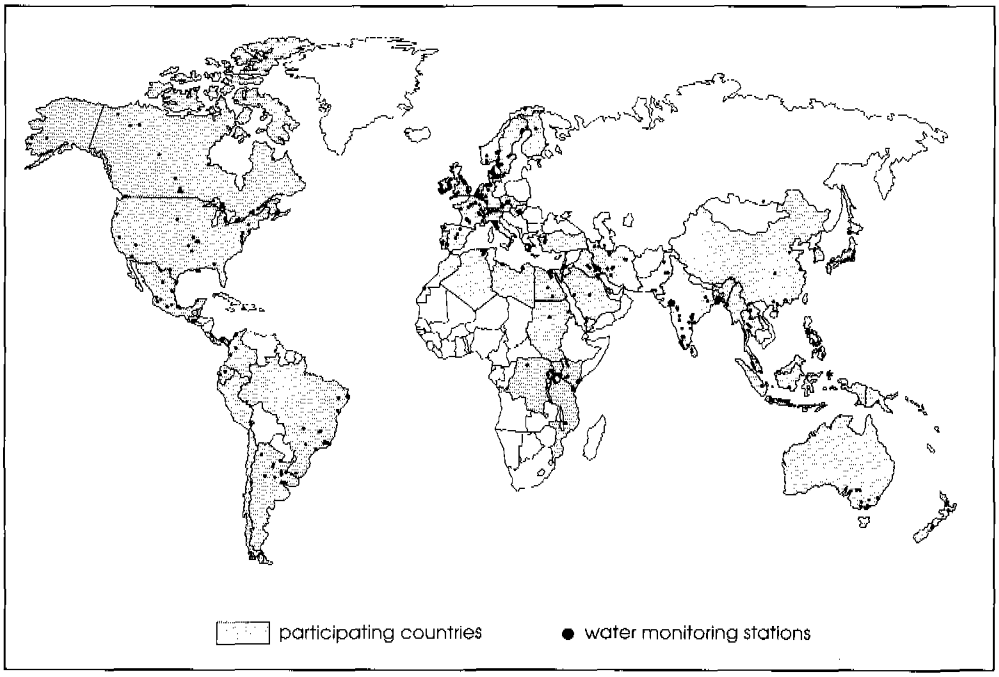
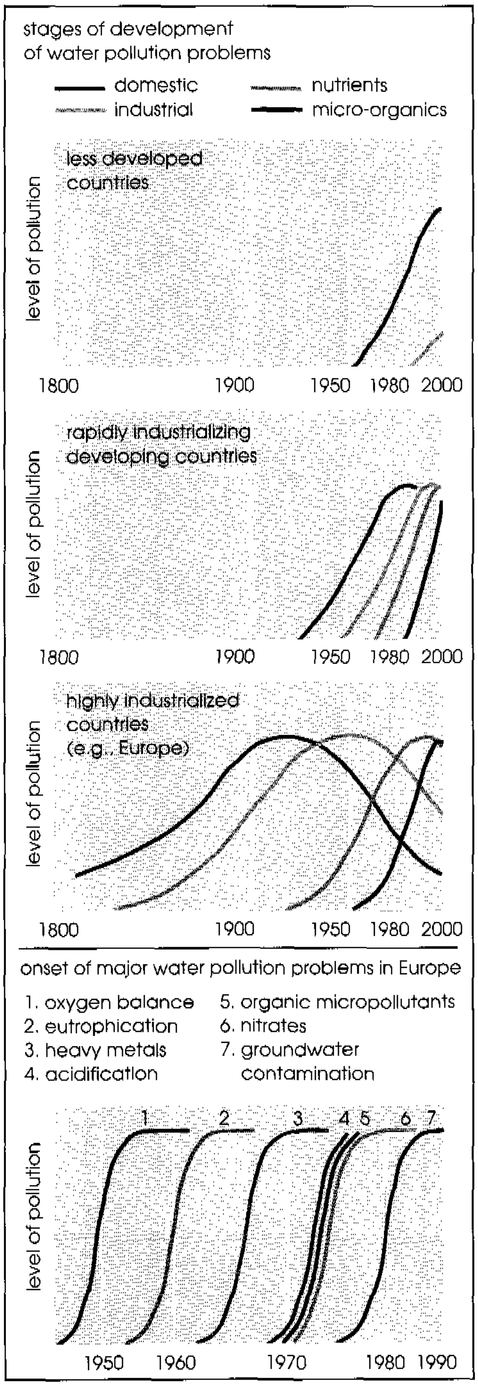


Figure 4 Map shows the countries that participate in the GEMS/Water monitoring system, and the location of the 344 stations involved.

Figure 5
Industrialized countries have undergone four major stages of freshwater pollution (third graph down). Countries at different stages of socio-economic development experience similar sets of problems at later dates. Bottom graph shows a more detailed presentation of the progress of water pollution problems in Europe.



Union and Eastern Europe), and not all pollutants are measured at each GEMS station. Therefore the GEMS assessment drew on additional data—national, regional and global monitoring reports, and scientific journals and publications—to supplement the GEMS/Water database and provide a more representative report.

This publication provides a summary of the major findings and conclusions of that assessment. It deals with the findings related to contamination by pathogens, organic matter, nutrients, heavy metals, organic micropollutants, atmospheric emissions, suspended matter and salinity.

One of the major conclusions of the assessment was that the nature and level of freshwater pollution depends strongly on socio-economic development. The industrialized countries, for example, have experienced a series of freshwater pollution problems involving domestic, industrial and agricultural wastes. Legislation has been adopted to curb each wave of problems as they arose. Today, pollution from industrial wastes is beginning to be controlled—but issues connected with acidification, organic micro-pollutants, nitrates and groundwater contamination are on the ascendant (*see fourth graph of Figure 5*).

Similar chains of events are likely to occur in the non-industrialized countries, though on different time-scales. As Figure 5 shows, a similar sequence of events is occurring in the industrializing developing countries, though the problems are appearing later on and are likely to succeed one another more rapidly than in the industrialized countries. In developing countries, where industrialization is still proceeding slowly, there are currently few water pollution problems—except those caused by domestic waste.

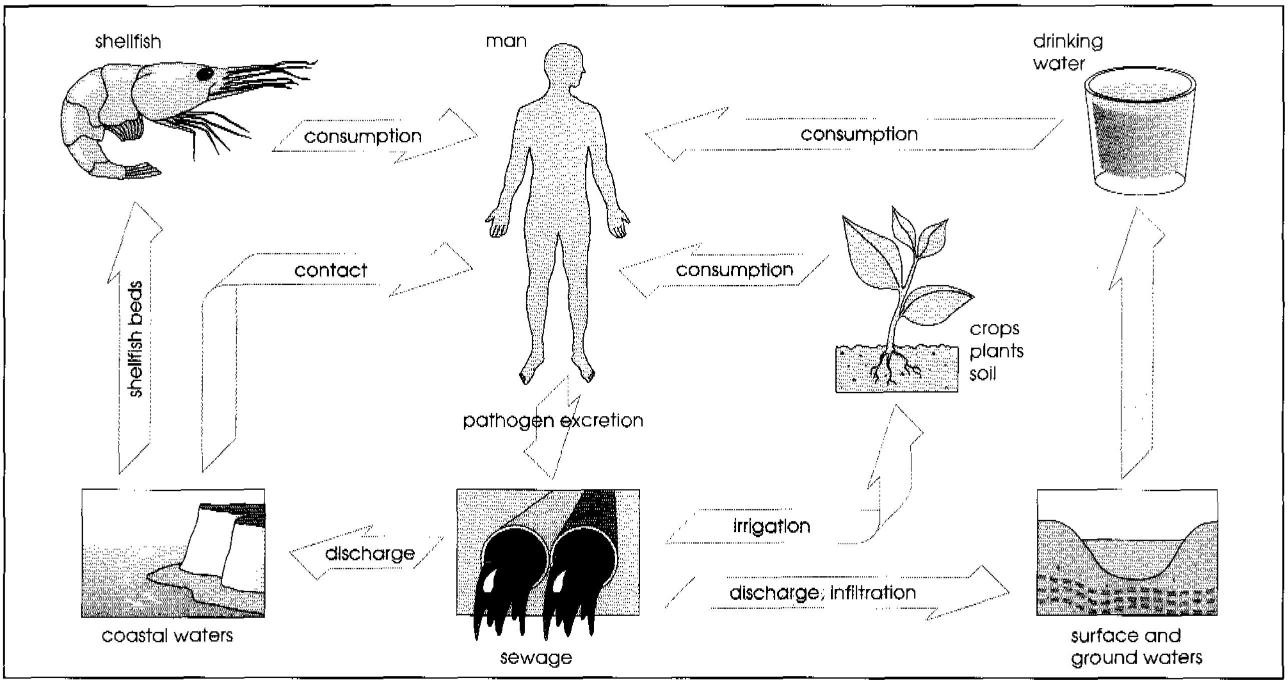
Pathogens

The GEMS/Water assessment found organic material, from domestic sewage, municipal waste and agro-industrial effluent, to be the most common water pollutant. This organic waste includes faecal material, some of which may be infected by pathogens such as viruses, bacteria and other biological organisms causing water-borne infections such as hepatitis A and gastro-enteritis. These pathogens come primarily from sewage that is discharged directly into water courses. Pathogens can also enter water supplies from stormwater run-off, or as a result of soil percolation from landfills or from agricultural areas where minimally treated wastewater is used on crops. In developed countries, disposable nappies are an additional source of concentrated pathogens—16 billion a year are dumped in landfills in the United States alone.

Because water-borne pathogens are difficult to detect in the laboratory, water is instead tested for 'indicators'—easily measured organisms the presence of which indicates that water is contaminated with faecal matter. The most commonly used indicator of faecal contamination is the presence of bacterial micro-organisms called faecal coliforms, so faecal contamination is often expressed as the number of faecal coliforms per 100 ml of water.

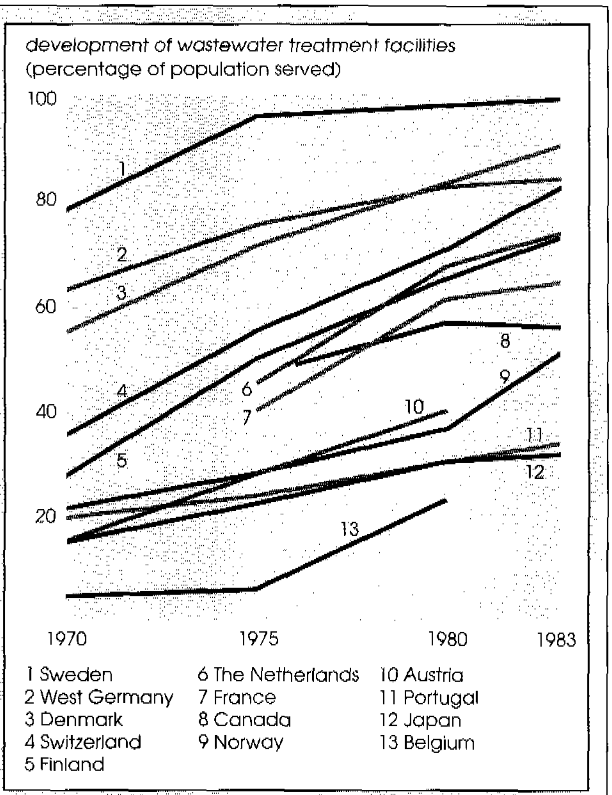
According to WHO, total coliforms in drinking water should not exceed 10 per 100 ml, and faecal coliform concentrations should be zero per 100 ml. Only 20 of the 110 GEMS river stations reported levels below the former or at the latter guideline. The risk to human health is limited if municipal water supplies are treated and disinfected, as they are in most developed countries. This is not the case in much of Asia, and Central and South America, where high faecal coliform counts in drinking water are reflected in high infant

Figure 6 A complicated chain of pathways leads to human exposure to water-borne pathogens. The main protection against infection remains the treatment of domestic water supplies—though legislation to control infection from other routes is increasingly employed in developed countries.



The importance of sewage treatment

Domestic and municipal sewage can seriously affect water quality by introducing three main pollutants—pathogens, organic matter and nutrients. Rapid urbanization can intensify such contamination if the capacity of existing sewage treatment facilities is exceeded, increasing the risk of poorly treated sewage being discharged into rivers and polluting drinking water supplies downstream. The problem is particularly serious in developing countries where urban expansion often outstrips provision of new water treatment facilities. More than 80 percent of all illness in the developing world is due to inadequate, unsafe water supply and sanitation facilities—some 4 million children a year die from diarrhoea caused by water-borne pathogens. Two-thirds of the world population lacks adequate sanitation facilities, and only 50 percent of urban dwellers have proper sewage disposal. Even in OECD countries, the population served by wastewater treatment plants in 1980 ranged from 2 percent in Greece to 100 percent in Sweden. Currently, sewage and water treatment cannot be quickly provided to all who need it and even in advanced countries it can only be effective in reducing microbial water content if adequately monitored.



mortality rates from diarrhoea and gastro-intestinal infections that are found in these areas. For example, a 1982 report claimed that the stretch of the Yamuna River that flows through New Delhi contained 7500 faecal coliforms per 100 ml water before entering the city and left with 24 million faecal coliforms per 100 ml. This dramatic increase was due to the 200 million litres of raw sewage dumped into the river daily.

Contamination from raw sewage is not a problem confined to the developing world. A 1989 bathing water survey for British beaches showed that 24 percent of the sites studied failed to conform to standards set by the European Community 15 years ago—mainly because of sewage contamination. A mere 8 'designated beaches' fell within the newer, stricter guidelines adopted by other EC countries.

More than two-thirds of the GEMS/Water groundwater monitoring stations—primarily in developing countries—reported faecal pollution, whereas baseline stations, far from human activity, had low levels of contamination. Many streams and rivers in South America, India and South-east Asia are heavily contaminated with bacterial and faecal matter, mainly as a result of lack of sewage treatment plants. Data for Africa were not available but are probably similar to those for other developing areas in arid or semi-arid zones.

Table 4 shows the faecal coliform counts in selected GEMS rivers during the period 1979–84. Almost all rivers have faecal coliform levels above those recommended for domestic use and bathing.

Contamination of rivers by region (numbers of rivers with different levels of contamination)

total coliforms/ 100 ml	*North America*	*Central and South America*	*Asia*	*Europe and Pacific*
<10	8	0	1	1
10		WHO guideline for drinking water		
10–99	4	1	3	2
100–999	8	10	9	14
1000–9999	3	9	11	10
10 000–99 999	0	2	7	2
>100 000	0	2	0	3

Organic matter

More organic matter is discharged into watercourses than any other pollutant. This organic matter contains a wide range of carbon compounds, the primary source of which is domestic sewage, but industrial effluents, such as those from tanneries, paper mills and textile factories, are also significant sources.

Organic matter is broken down in water by aerobic microbes. The oxygen required for this process is taken from the surrounding water, thus diminishing its total oxygen content. Large amounts of organic matter cause severe oxygen depletion in water, which is then unable to support both the decomposition of organic compounds and many forms of aquatic life. The amount of oxygen required for microbial decomposition can be measured as biochemical oxygen demand (BOD).

The two other most common variables used to estimate amounts of organic matter present in water are the chemical oxygen demand (COD)—the oxygen required to oxidize the organic compounds using a powerful chemical oxidant; and the oxygen saturation, expressed as a percentage of water's oxygen-carrying capacity. Data indicate that about 10 percent of the rivers where GEMS measured both BOD and COD are polluted by organic matter—with a BOD of more than 6.5 mg/l or a COD of more than 44 mg/l; and 5 percent of the rivers are severely oxygen-depleted (having less than 55 percent saturation).

Oxygen balance indicators in GEMS rivers
(percentage of stations reporting values ≤ values shown)

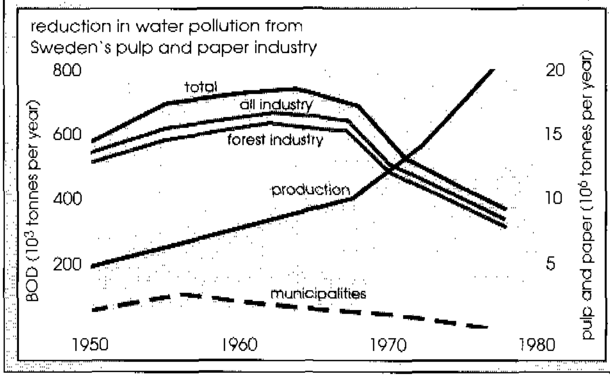
	5%	10%	50%	90%	95%	number of stations
BOD (mg/l)	1.3	1.6	3	6.5	9	190
COD (mg/l)	4	6	18	44	60	127
O_2 saturation (%)	55	70	90	105	110	227

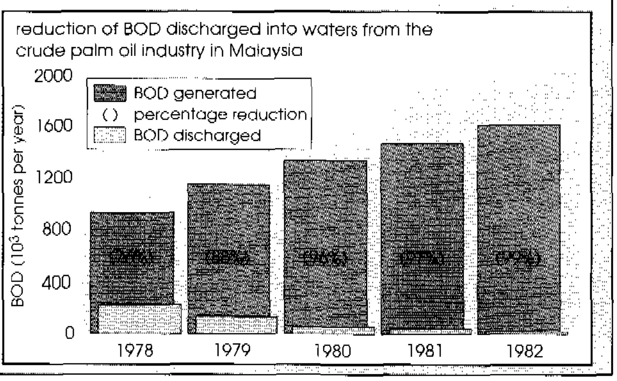
Table 5 GEMS data on oxygen indicators show that some 10 per cent of the GEMS rivers where both BOD and COD were measured are polluted, in that they have BODs of more than 6.5 mg/l and CODs of more than 44 mg/l.

Industrial effluent controls

In developed countries, installing wastewater treatment plants has helped reduce organic matter pollution considerably. Reducing industrial effluents at source—before discharge into water bodies—must be the next step. Sweden has already halved its national organic matter discharge—while simultaneously increasing production—by controlling effluent from pulp and paper industries, as well as that from municipalities.

In developing countries, treatment plants are badly needed to deal with organic waste from urban and industrial areas. Malaysia has significantly reduced organic waste loads from its palm oil mills, thereby improving water quality, while the mills' overall production continues to increase.



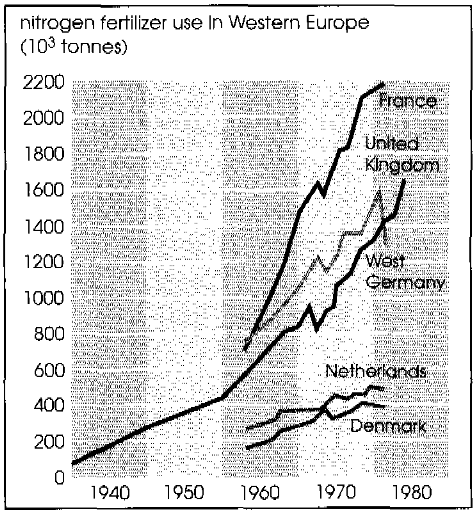


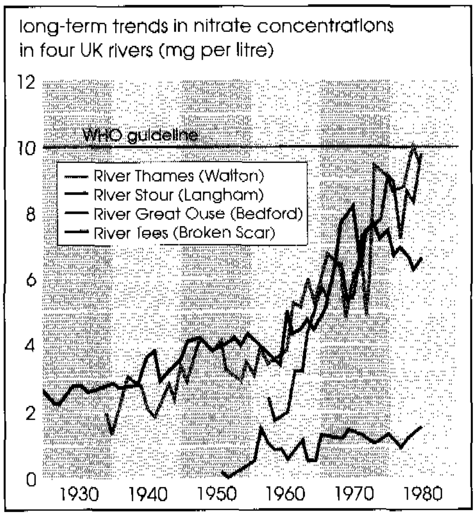
Nutrients

Small doses of nutrients are essential to the metabolism and growth of all aquatic organisms. But man-made sources of nutrients—such as the organic matter in municipal waste water and run-off from fields fertilized with chemicals and manure—can upset the natural balance of organisms living in water.

In many cases, nitrogen and phosphorus—the two most important nutrients—were found to be at levels far above those monitored by the GEMS/Water background stations. The median nitrate level at impact stations is 7 times the average for an unpolluted river; and the median phosphate concentration is 2.5 times the unpolluted average. In the 10 percent of rivers with the highest nitrate concentrations, levels range from 9 to 25 mg/l—thus many exceed the WHO guideline of 10 mg/l for nitrates in drinking water. The 10 percent of rivers containing the most phosphorus have levels of 0.2–2.0 mg/l, which is 20–200 times higher than the average for unpolluted rivers. European rivers have by far the highest average levels of nutrients: in some cases nitrate levels are 45 times the natural background concentrations.

Figure 7 Graphs right and below right, of fertilizer use in Western Europe and of nitrate levels in four UK rivers, show the high correlation that exists between fertilizer use and levels of nitrates in rivers.





This nutrient overloading of water bodies, primarily with nitrogen and phosphorus, causes eutrophication of lakes and reservoirs by promoting abnormal plant growth (seen as algal blooms) that then deplete oxygen as they decompose.

More worrying are high nitrate levels in drinking water, which have potentially serious consequences for human health. The major non-point sources in Western Europe and the United States are nitrogen fertilizers and manure used for intensive agriculture.

World fertilizer use appears to be increasing especially in developing countries, and particularly where intensive irrigation allows for double- or triple-cropping. Use of nitrogen fertilizers increased two- or threefold in many countries during 1961–81, and application rates are expected to keep rising, leading to worse leaching in future. But the problem is not confined to developed countries with intensive agriculture. In developing countries, such as India and Nigeria, seepage from pit latrines or septic tanks can produce high nitrate levels in ground water.

The definition of a 'safe' level of nitrates

Eutrophication

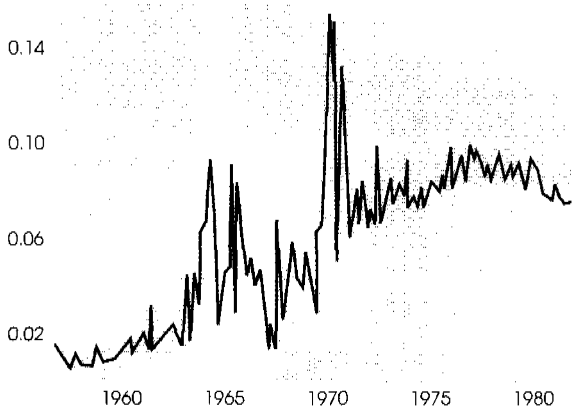
The enrichment of waters with nutrients, especially phosphorus and nitrogen, is called eutrophication. It can lead to enhanced plant growth (algal blooms) and depleted oxygen levels as this plant material decays. Although not always man-induced, the problem is often linked to organic waste and agricultural run-off. The first signs of eutrophication came to light about 30 years ago. Today, 30–40 percent of the world's lakes and reservoirs are eutrophic—and the figure is rising.

It is difficult to assess the extent of global eutrophication, but it is an established problem in many lakes and reservoirs in highly populated, industrialized countries. One-third of Spain's 800 lakes are eutrophic, for example, and South Africa, Australia and Mexico are also affected. Eutrophication is also starting to spread to some rivers (the Loire is the most eutrophic in Western Europe) and coastal waters, such as areas of the Chesapeake and Manila Bays.

In some areas badly affected by eutrophication, such as the smaller North American Great Lakes and the Scandinavian lakes, the situation is slowly being reversed. There, laws have been introduced to reduce or replace tripolyphosphates (used mostly in detergents) as have measures to remove phosphorus from wastewater. Not all intervention has been successful but eutrophication is reversible if mid- and long-term strategies are enacted. Austria, Denmark, Germany, Sweden, and Switzerland already have relevant legislation. Only 20 percent of Sweden's wastewater is discharged without first eliminating the phosphorus. In a 1972 treaty between Canada and the United States, the deterioration of the Great Lakes was acknowledged and partly reversed by legislating that 75 percent of wastewater should receive primary and secondary treatment before discharge into the basin. In Denmark, where chemicals used for intensive agriculture contribute to eutrophication in lakes and coastal areas, the government has set deadlines by which farmers must reduce their fertilizer use, or face high taxation penalties.

Although many of the world's lakes and reservoirs are affected by eutrophication to some degree, it is the smaller ones that are most often affected. Larger lakes, including Baikal (which contains 20 percent of the world's fresh water), Superior and Malawi are still almost unscathed.

development of eutrophication in Lake Geneva as indicated by total phosphorus levels (mg per litre)



in drinking water is still debated but there is concern, especially in Europe and other areas relying on groundwater supplies, that concentrations are too high. In the United Kingdom during 1983–84, 125 groundwater sources supplying 1.8 million people exceeded the WHO nitrate guideline of 10 mg/l most of the time. Moreover, evidence suggests that without substantial changes in agricultural practices, nitrate levels in most of Britain's unconfined aquifers will eventually exceed this limit. It is difficult to assess the effects of excess nitrates on humans. Although it is well known that nitrites (a product of nitrate reduction) can cause methaemoglobinaemia in bottle-fed babies and the elderly, the link between nitrates in water and cancer is more difficult to prove because humans also ingest nitrates in food.

Heavy metals

The heavy metals include cadmium, chromium, copper, lead, nickel and zinc. Estimated figures for their output so far mined and thus ultimately released into the atmosphere and biosphere are: cadmium—0.5 million tonnes; chromium and copper—310 million tonnes each; lead—240 million tonnes; manganese, mercury and nickel—20 million tonnes each; and zinc—250 million tonnes. Arsenic, though not a heavy metal, is frequently monitored along with the heavy metals due to its high toxicity.

Heavy metal pollution of water has a number of man-made causes including the processing of ores and metals; the industrial use of metal compounds (chromium in tanneries, for example); and, particularly, leaching from domestic and industrial waste dumps, mine tailings, contaminated bottom sediments and lead pipes. This kind of leaching has potentially acute consequences. Acidified or saline water enhances metal mobility, so drawing more lead from piping, or other metals from mine tailings; it also transforms the metal into a form more readily absorbed and stored in living tissues, thus amplifying the toxic effects of leaching.

The heavy metals have so far affected water quality only on a local or regional—rather than global—scale, though pollution from lead now occurs globally in coastal and marine environments. In developing countries, large-scale mining or smelting operations often result in severe pollution downstream because of lack of control installations. Assessing the extent and severity of heavy metal pollution is difficult due to problems of sample collection and processing. The most complete analyses have been provided by stations on 20 US rivers. The GEMS assessment found heavy metal contamination in several rivers in Chile,

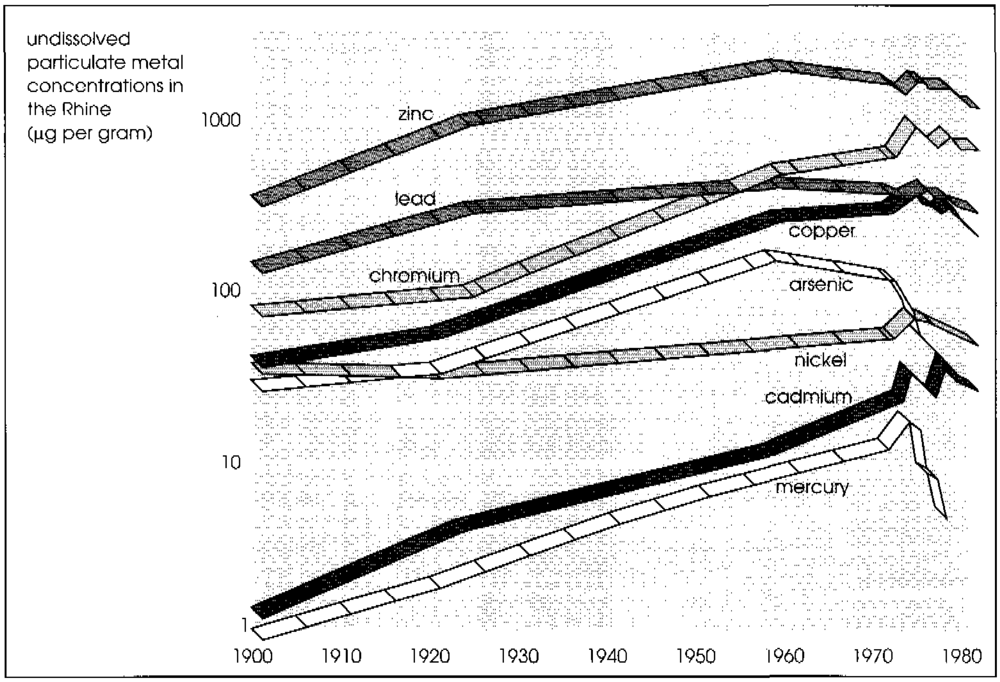


Figure 8 Trends in undissolved heavy metal and arsenic concentrations found in The Netherlands section of the Rhine. Control measures adopted since the early 1970s have now reduced heavy metal concentrations considerably.

China, Japan, Mexico, Panama, the Philippines, Turkey and the United States.

The Rhine river basin, which supports 40 million people and 20 percent of the world's chemical industry, is managed by Switzerland, France, Germany and The Netherlands. Until the 1970s, the Rhine was severely polluted with cadmium and mercury, but levels have been sharply reduced since 1971 through improved wastewater treatment and the replacement of some metals in industrial applications.

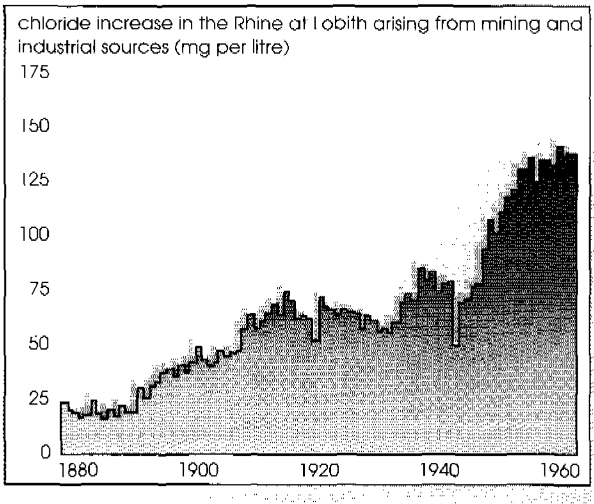
Lead levels in the blood of Americans and Europeans are two to three times higher than those found in non-technological societies. Although much of this increase has resulted from breathing fumes from cars using leaded fuel, mobilization of lead from older domestic piping systems is also responsible. Since the United States introduced the Clean Air Act of 1970, making catalytic converters and unleaded petrol obligatory for all cars manufactured after 1974, lead levels in blood have dropped dramatically.

'Safe' levels of metal concentration are hard to establish and vary according to type and degree of exposure and the state and toxicity of the metal in question. Acute human intoxication from heavy metal pollution is not yet common. Toxicity is particularly difficult to measure because effects may not show up for years, or levels may become toxic to humans only through bioaccumulation in aquatic organisms. For instance, trace levels of elements such as lead, zinc and cadmium may cause damage to human health through long-term exposure. The consumption of sea food that has absorbed concentrated methylated mercury to a level toxic to humans could have a serious effect within months if eaten exclusively.

Mining

Mining can release heavy metal compounds directly into surface waters and may result in the leaching of pollutants from mine tailings into groundwater, particularly in areas where acidic water causes high metal mobility. One of the most serious cases of metal poisoning caused by mining occurred in the late 1940s when cadmium—leached from mine tailings and absorbed by rice crops near Japan's Jintsu River—caused 'Itai-Itai' disease in inhabitants for the next 20 years.

Large amounts of extremely saline wastewater—a by-product of some types of mining—are also a potential pollutant. Drainage from potash mine tailings in Alsace and salt mines in Lorraine, for instance, have been partly responsible for raising the Rhine's salinity levels by a factor of seven since 1880, preventing the use of Rhine water in greenhouse cultivation in The Netherlands. The practice of placing highly saline water in evaporation ponds or pits, where it sometimes seeped into and contaminated underlying aquifers, was banned in the United States in the 1960s; other anti-pollution measures include lining the pits to prevent seepage or injecting wastewater back into the ore-bearing rock.


chloride increase in the Rhine at Lobith arising from mining and industrial sources (mg per litre)

Organic micropollutants

Organic micropollutants—chemical substances such as DDT, PCBs and industrial solvents—originate primarily in industries such as coal mining and petrol refining, and in textile, wood pulp and pesticide factories. They are released into the environment through urban and agricultural run-off, atmospheric fall-out, and urban and industrial wastewater. Organic compounds are also found in substances for domestic use, such as household solvents and aerosol containers. Because these compounds are commonly used, their rate of dispersal into the environment is correspondingly high.

More synthetic organic compounds are introduced every year, often without a full understanding of the risk they pose to the environment in general and human health in particular. They can have two effects on humans: immediate short-term toxicity and reactions from long-term exposure, both of which can result in chronic symptoms and death. Worryingly, there is now evidence that disinfecting public water supplies with chlorine (to eliminate pathogens) might actually lead to the formation of volatile halogenated derivatives, some of which are known carcinogens.

An assessment of global organic micropollution is difficult and monitoring of micropollutants in freshwaters is often not included in routine national monitoring programmes—developing countries, particularly, often lack the means and equipment to test for and analyse organic micropollutants. Between 1979 and 1984 data on organochlorine pesticides (DDT, aldrin, dieldrin) as well as polychlorinated biphenyls (PCBs) were reported at only 25 percent of the GEMS/Water stations. Concentrations of organic micropollutants were generally below 10 ng/l, and more often between 3–7 ng/l in US and Canadian rivers, as well as at most stations in several European countries (The

Table 6 Levels of chlorinated hydrocarbons (in insecticides and PCBs) were below 10 ng/l at most of the stations monitored by GEMS/Water, 1979–84; high levels were found only in developing countries.

levels of contamination	*<10 ng/l*	*10–50 ng/l*	*100–1000 ng/l*	*>1000 ng/l*
Africa				Tanzania (1): dieldrin
Americas	Canada (5) USA (12)			Colombia (1): dieldrin, DDT
Asia	Thailand (3) Japan (5) Malaysia (5)		China (4): HCH Japan (3): PCB Thailand (1): DDE	Indonesia (11): PCB Malaysia (1): dieldrin
Europe	Finland (5) Netherlands (6) UK (7)	Belgium (1): DDE Finland (1): DDT Spain (6): DDT UK (1): DDT, aldrin, dieldrin, HCH	UK (1): PCB	
Oceania		Australia (1)		

The numbers in brackets indicate the number of monitoring stations. Unusable data (detection limit too high): Portugal, Japan (PCB), Philippines, New Zealand

Netherlands, Finland, the United Kingdom) and Asia (Malaysia, Japan and Thailand). Markedly higher levels (100–1000 ng/l) were reported for the River Trent in the United Kingdom (PCBs), from the Chinese river stations (HCH isomers), and from several Japanese monitoring stations (Lake Biwa and the Yodo and Ohta rivers). Serious levels of contamination (more than 1000 ng/l) were found in some rivers in Colombia (DDT and dieldrin), Indonesia (PCBs), Malaysia (dieldrin) and Tanzania (dieldrin). Generally, data do not show pesticide pollution to be a significant problem in other Asian, or North American and European rivers.

It is impossible to generalize about the potential toxicity of organic micropollutants because there are so many of them, all with different derivatives; and not all laboratories are equipped to detect low (but possibly still harmful) concentrations. Judging by the limited pesticide monitoring that has been carried out at a few GEMS/Water stations, concentrations of DDT, aldrin and dieldrin (all chlorinated insecticides) in some groundwater aquifers probably exceed guideline limits.

Although the use of DDT was banned in most developed countries in the 1960s, other pesticides—mainly herbicides—are used heavily in North America, Europe and Japan. Rapidly developing countries are also increasing their use of these chemicals, tending to use more insecticides; Barbados imported 400 percent more pesticide between 1968 and 1981. Pesticides leached or drained from cultivated land into surface waters and underlying groundwater are a serious form of pollution because of their environmental mobility and persistence.

Crop spraying in Jamaica. Many developing countries have yet to introduce rigorous controls for pesticide use—levels of organic micropollutants are often higher in developing countries than in developed ones as a result.

Atmospheric emissions

Atmospheric emissions, mainly those containing sulphur and nitrogen oxides from fossil-fuel combustion, are the primary cause of acid rain and, consequently, acidified fresh water. Once in the atmosphere, sulphur and nitrogen are oxidized and then react with atmospheric moisture to form acids. They are then returned to Earth through wet (rain, mist, fog, snow) or dry deposition, gradually decreasing the pH of water and soils which are not well-buffered—acid-sensitive soils are usually underlaid by non-calcerous bedrock with little capacity to neutralize incoming acid.

Acidified fresh water was first noted in Sweden and Norway but is now found in eastern North America, much of northern and central Europe, and in some of the rapidly industrializing developing countries. The industrialized countries are overwhelmingly responsible for acid deposition, contributing about 90 percent of global man-made emissions. Sulphur emissions have declined by 15–40 percent in Western developed nations since 1970 mostly because of control policies. Precipitation containing sulphur dioxide (SO_2) exceeding 1.5–2 mg/l can be found in rapidly developing areas of Asia and South America, as well as in Japan and South Africa. In southern China, where the soil is already fairly acidic, acid deposition is emerging as a major ecological concern for the near future. Anthropogenic nitrogen emissions have either stabilized or increased in industrialized countries since the 1970s because there are less regulations pertaining to nitrogen emissions than to sulphur emissions and because of an increased number of cars.

Assessment of freshwater acidification trends is usually made by comparing historical with recent data on pH, alkalinity and on sulphate concentrations. The GEMS/Water network collects current data

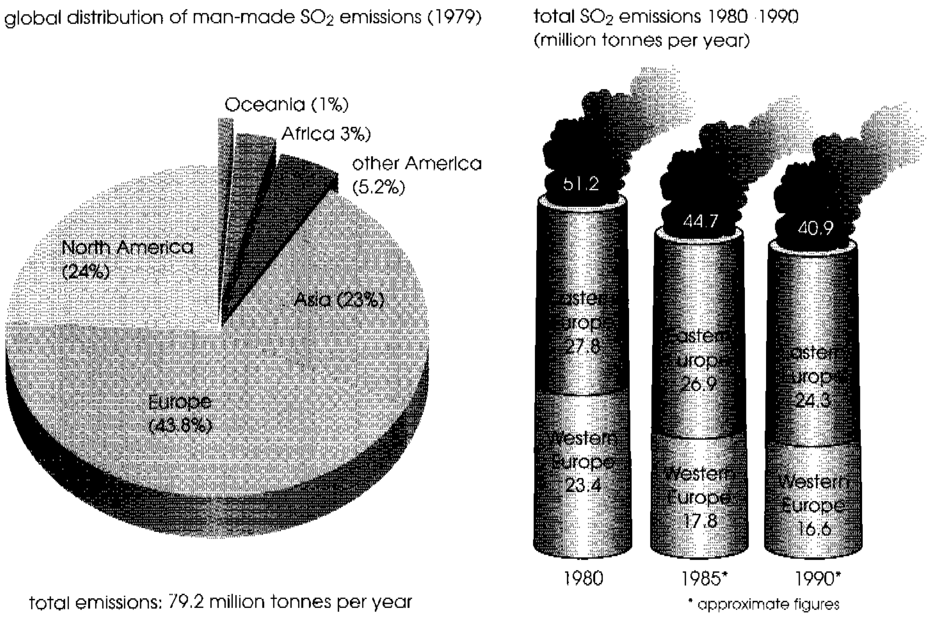


Figure 9 Pie chart on the right shows that Europe and North America produced more than two-thirds of global SO_2 emissions in 1979. The falling levels of SO_2 emissions shown far right are typical of many industrial countries, and result from the introduction of emission regulations.

on these, but lacks the historical data required to assess long-term trends. Extended records are available only for a few lakes in Scandinavia, the United Kingdom, The Netherlands and eastern North America. However, using fossilized algae preserved in lake sediments, past pH levels can be reconstructed and compared with present values, showing that certain lakes in acid-sensitive regions have become more acidified over the past 100 years.

The first, most obvious impact is on aquatic life, which generally cannot survive in fresh water with a pH below 5 without impairment to reproduction. The main effects on humans result from increased exposure to potentially toxic metals. Trace elements are leached from soil and distribution pipes by acid water, ending up in water supplies and food chains. Surveys of lakes in Scandinavia, Scotland and parts of the north-east United States have consistently shown that the lower the pH, the higher the levels of aluminium—often reaching levels above the 0.2 mg/l WHO guideline. Increased acidity may also raise levels of copper, arsenic and mercury. Large municipal suppliers try to alleviate such potential problems by bringing the pH for drinking water up to between 7 and 9 but this does nothing to help the many using untreated water—1.5 million in the north-eastern United States alone. One short-term, extremely costly, 'band-aid' solution to acidified fresh water is liming, which involves dumping large quantities of lime into water to neutralize the acid and bring the pH back to normal. Sweden started liming roughly 4000 of its affected lakes in 1977, with the result that some forms of aquatic life have been restored.

Acidification in Scandinavia

In the 1950s and 1960s, emissions of SO_2 and NO_x from industrial centres in central Europe and the United Kingdom were linked to environmental damage in Scandinavia. This was the first noted case of trans-boundary air pollution, and it spurred further research into the causes and effects of acid deposition everywhere. Since the mid-1900s, the pH of many lakes in southern Scandinavia has fallen by 0.5–1.5 pH units, with serious consequences for aquatic life and potential implications for human health.

The most important health effect of acidified water comes from its ability to leach trace metals from soil and distribution pipes. Private wells in western Sweden, for example, have aluminium levels of up to 1.7 mg/l, whereas the WHO guideline for drinking water is only 0.2 mg/l. High levels of methyl mercury can also cause problems, particularly when it becomes accumulated in fish that are then eaten by humans.

In 1985 nation-wide inventory of 6908 Swedish lakes, selected specially to give extrapolation values for the total of around 83 000 lakes found that, of this total: 4600 had a pH below 5, the worst affected being the smaller lakes in the south and south-west; 4000 could not support fish at all; and 17 000 had reduced populations of acid-sensitive species such as roach and crayfish.

Numbers of Swedish lakes by pH and size, winter 1985

pH	*≤4.9*	*5.0–5.9*	*6.0–6.9*	*≥7.0*
>100 km^2	0	0	9	13
10–100 km^2	0	2	260	100
1–10 km^2	28	380	3000	590
0.1–1km^2	600	4400	12 700	1550
0.01–0.1 km^2	4000	24 500	28 500	2700
all sizes	4600	29 000	44 000	5000

About 400 sampled lakes had been limed at least once.

Suspended matter

Suspended particulate matter (or SM) consists of materials that float in suspension in water. They have three main sources—natural soil erosion, matter formed organically within a water body, and material produced as a by-product of human activity. SM particles can make water unsuitable and unpleasant to drink and are also major carriers for many organic and inorganic pollutants, including most toxic heavy metals, pathogens and nutrients.

Once in slow-moving or still waters in rivers, lakes, deltas and estuaries, SM settles on the sediment bed and forms deposits. Evidence of man-induced SM from Roman and Mayan times has been discovered in lake beds, making this one of the first types of water pollution. Human activities that cause or increase the rate of erosion, such as deforestation, damming, agriculture and mining, add to the level of SM in rivers and lakes. Deforestation can raise a river's SM more than 100 times.

SM is one of the simplest variables of water quality to measure. GEMS/Water measures SM at 52 percent of its river stations (137) and at more than 50 percent of its lakes. As for many other variables, Africa was the least-surveyed continent. Average global levels are hard to obtain because of vast natural variability and the bias inherent in naturally turbid rivers. However, GEMS/Water data indicate high levels of SM in China, India, Indonesia, Iran and Iraq. In North America and Asia, where problems such as soil erosion, reservoir silting and flood plain deposition are apparent, SM levels are measured more frequently and more thoroughly. The US National Stream Quality Accounting Network (NASQUAN), for example, samples more than 300 rivers a month.

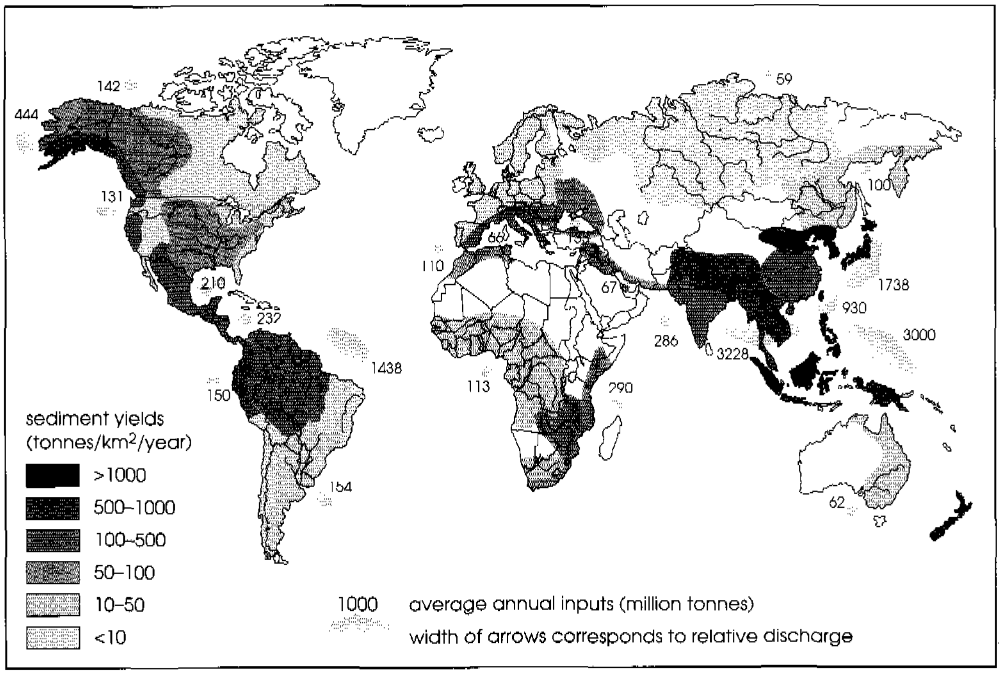


Figure 10 Annual average discharges of sediment (in millions of tonnes) from the world's major drainage basins. Width of arrows corresponds to relative discharges. As the map shows, the major silt-bearing rivers are in South America, China and South-east Asia.

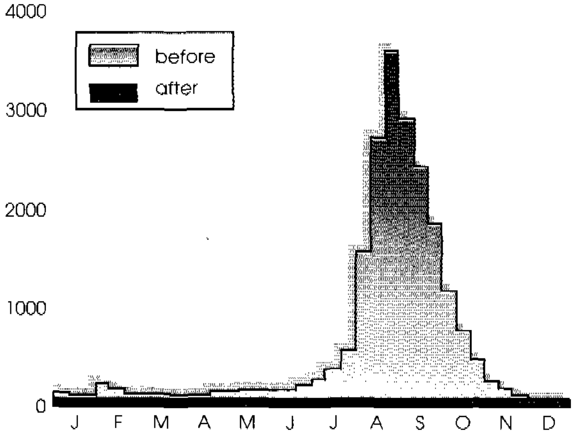
Dams and reservoirs

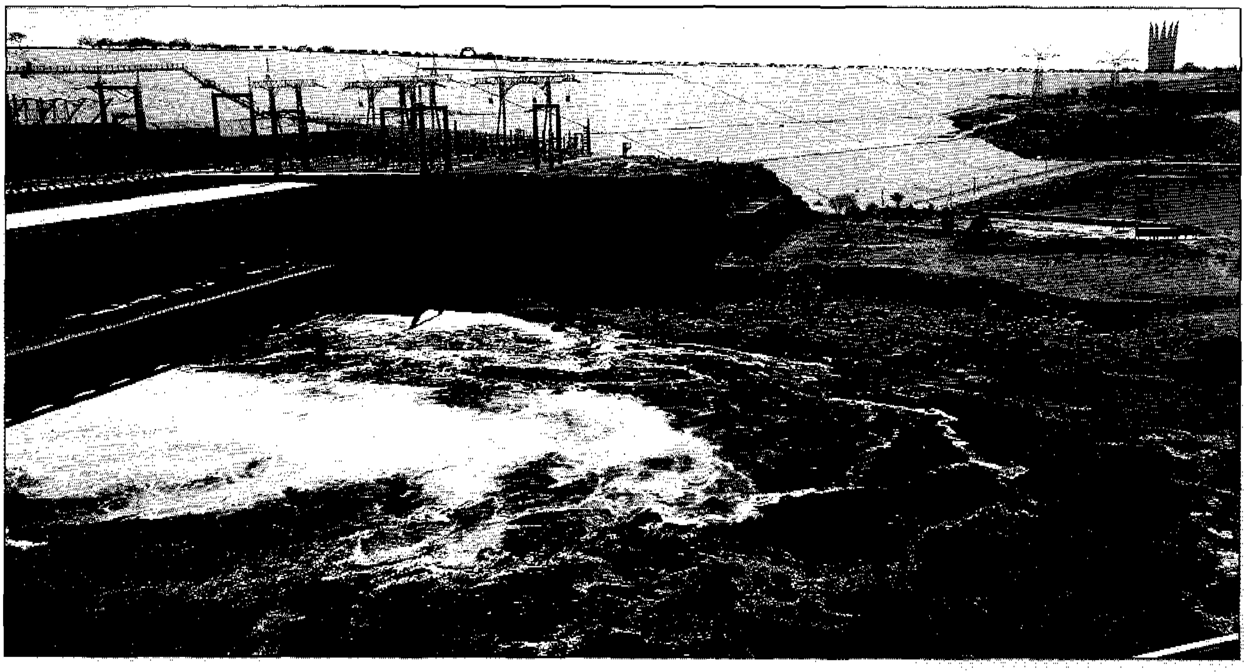
River damming affects the budget of SM flowing from rivers to the oceans. This is because reservoirs act as effective sinks for SM—an estimated 10 percent of the global SM discharge to the sea is in fact trapped annually in reservoirs. Since the closure of the Hoover Dam in 1930 on the Colorado River, SM discharge has dwindled from about 2000 tonnes per year to practically nothing.

River damming can also greatly modify water quality. Waters flowing out of reservoirs have reduced SM quantities, are depleted of nutrients and are often more saline with consequent detrimental effects on downstream agriculture and fisheries. Enhanced eutrophication resulting from longer water residence time is often observed in reservoirs in subtropical areas. Periodical dredging and reduction of accumulated SM settling on the bottom of reservoirs may also result in increased ammonia concentrations and greater turbidity downstream.

Despite these obvious drawbacks, most of the world's major rivers are now dammed, including the Volga, Tigris, Indus, Zambezi, Volta, Nile, and Mississippi. It is estimated that about 25 percent of the water currently flowing to the oceans has been previously stored in a reservoir.

annual variations in sediment concentration in the Nile before and after closure of the High Dam at station Gaafra (mg per litre)





Egyptian Tourist Board

Salinity

Increasing salinity is a significant and widespread form of freshwater pollution, particularly in arid, semi-arid and some coastal regions. It is not a new phenomenon—6000 years ago, salinization of soil and water in the floodplain of the Tigris and Euphrates rivers contributed to the decline of Mesopotamian civilization. Some 80 percent of the area is still affected.

Salinity is caused primarily by a combination of poor drainage and high evaporation rates that concentrate salts on irrigated land and occurs mainly in arid and semi-arid regions that rely on irrigation for crop production. Another cause of salinity is the overpumping of coastal aquifers, which leads to the intrusion of saline water. Local increases in salinity have also been caused by the use of salt to prevent icing on roads, as a side-effect of mining and a result of the disposal of the saline water that is produced during oil production. None of these issues compares in importance with the problem of salinity introduced as a result of irrigation.

Irrigation accounts for 73 percent (approximately 3300 km^3 per year) of global water use. Some 270 million hectares of cropland are currently irrigated; they produce 30 percent of the world's food, and all but 15 percent of them are in arid or semi-arid areas. About 60–80 million irrigated hectares are affected by salinity to some extent, and a further 20–30 million hectares are severely affected. According to one estimate, the area of land that goes out of production annually as a result of salinity is equal to 30 to 50 percent of the area of new land put down to crops for the first time.

Waterlogged soil, which adds to the problem of salinity, is usually caused by overwatering and a lack of proper drainage systems. Although much of the excess water leaves the fields as surface run-off, some sinks in, giving rise in time to waterlogging. In this way groundwater levels can be raised to within a metre or so of the surface. When this happens, 'secondary' salinization may result, caused by the groundwater bringing to the surface salts that it has dissolved from the aquifer, subsoil and root zone.

Salinity is now a problem in the Nile valley, for example, because of year-round watering (possible since the Aswan High Dam was built), lack of adequate drainage from the fine-grained alluvial soils, and high evaporation rates. The latter force farmers to apply more water, which only aggravates the situation by causing

Countries with the largest areas of irrigated land severely affected by salinity

	total irrigated area		*area affected by salinity*	
	(million ha)	*(year)*	*(million ha)*	*(year)*
India	41.8	1986–88	12	1977
USA	18.1	1986–88	4	1985
Pakistan	15.9	1986–88	3.2 [1]	1987
Iran	5.7	1986–88	1.2	1977
Iraq	2.0	1986–88	0.45 [2]	1977
Egypt	2.6	1986–88	0.8 [3]	1970

[1] 80 percent of irrigated land is affected in the Punjab

[2] More than 50 percent of the irrigated land in the Lower Rafidain Plain is affected

[3] Mostly in the north part of the Nile delta

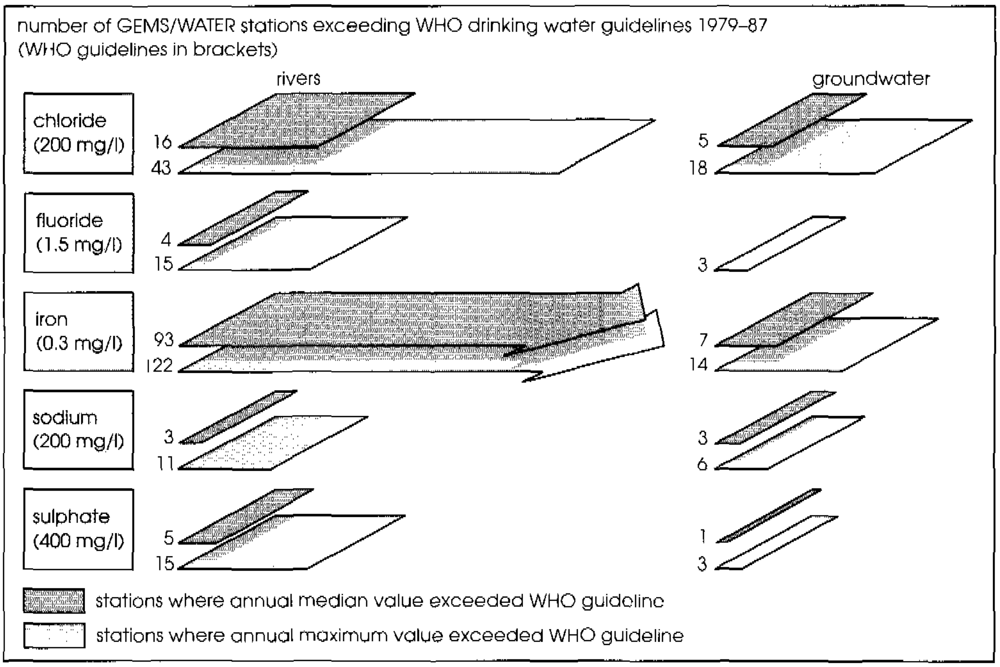


Figure 11 shows numbers of GEMS/Water stations where median and maximum values related to salinity exceeded WHO guidelines. Since many of the guidelines (apart from exceptions such as fluoride) are set for aesthetic reasons, rather than public health ones, the results are less alarming than at first sight.

waterlogging and secondary salinization. Although control measures are possible, they are expensive and are politically difficult to implement wherever more than one country is involved.

More efficient irrigation, such as trickle irrigation techniques, combined with effective drainage, is one answer. Israel already uses drip methods and sprinklers on half its irrigated land. Irrigation techniques are being improved elsewhere as well but there is a long way to go before salinity problems can be controlled. Open ditches, tile drains or pumping from wells can reduce or prevent waterlogging and salinity by lowering shallow water tables. Such measures have been taken in Pakistan and the Indus Plain, for example—but at considerable expense. Unfortunately, salinity—once it occurs—is hard to remedy. In Tadjikistan and Turkmenistan in the Soviet Union, a combined package of deep drainage, leaching of salts, vertical pumping of aquifers, lining of canals and sound water management has been introduced, showing that it is possible to halt and reverse salinization. But such examples are rare.

Conductivity, chloride concentration and alkalinity are the most widely measured variables related to salinity within the GEMS/Water network. They are measured at more than 75 percent of all stations, often more than 12 times a year. Figure 11 statistically summarizes the main GEMS/Water results; as the figure shows, many GEMS stations recorded saline levels in excess of WHO guidelines. However, since many of these guidelines were set for aesthetic reasons—the level of salinity that is acceptable to the human taste bud is rather low—this does not necessarily imply any health risk. Sodium chloride and sulphate concentrations were found to be high in Australia, Iran, north-west India and Mexico.

Implications for policy

Conclusions from the GEMS assessment

Polluted water has the potential for becoming a global threat. The 1988 GEMS assessment has shed light on some of the major issues threatening the quality of global freshwater resources. However, many unanswered questions remain.

The GEMS assessment of fresh water quality found that the main threats to human health are from sewage, nutrients, toxic metals and the chemicals used in industry and agriculture. The most widespread pollutant is undoubtedly faecal matter present in domestic sewage, which causes high levels of pathogens in water supplies that are not treated before use. Unacceptably high faecal coliform levels were found in two-thirds of rivers monitored, particularly in developing countries. In developed countries faecal contamination has been contained by waste treatment plants and by disinfecting public water supplies.

Run-off from agricultural areas fertilized with manure and chemicals pollutes water courses and groundwater by increasing levels of nutrients. Amounts of nitrate and phosphate were found to be particularly high—exceeding the WHO guideline for drinking water in many places—in European and US rivers and ground water, leading to extreme cases of eutrophication and concern over the effects of nitrates on human health. In the United Kingdom, 125 water sources supplying 1.8 million people exceeded the guideline of 10 mg/l for nitrates. Phosphate levels were on average 2.5 times higher in European rivers than in unpolluted water. But nutrient overloading and its effects are not confined to industrialized countries: about 25 percent of major Chinese lakes are also eutrophic.

Metal contamination usually occurs on a local or regional scale as a result of mining or industry in a particular area. In the Ruhr catchment in Germany, for example, about 55 percent of the heavy metals come from municipal and industrial wastewater treatment plants. Canada's Sudbury smelter has been a significant source of metal pollution, causing acute local contamination and contributing to heavy-metal deposition over a large part of Ontario and Quebec through long-range atmospheric transport. Mine tailings and industrial waste in landfills are also sources of metal contamination, such as from aluminium—especially when combined with acidic water.

Fossil-fuel burning is a subject of much concern. Not only do the gases released worsen the greenhouse effect, and hence may alter the climate, but they acidify both land and water through long-range atmospheric transport of nitrogen and sulphur oxide emissions. Industrialized countries have reduced sulphur emissions, but progress on nitrogen oxides is less encouraging.

Deforestation, river damming and destruction of wetlands are all taking their toll on water quality, though not actually introducing pollutants (apart from suspended matter). Destroying wetlands eliminates a vast natural filter and biodegradation system that could, in some areas, degrade many common pollutants and keep them out of water supplies.

Salinization, associated with irrigation, is a major problem in Sahelian Africa, parts of the Middle East and India. Many coastal aquifers have become unusable because of saline intrusion, caused by overpumping. Some European rivers, such as the Weser and the Rhine, have been contaminated by the leaching of salts from mine tailings.

Organic micropollutants were the most difficult of the pollutants to assess because of their relatively recent appearance, consequent lack of appropriate surveys, and ever-increasing numbers. Local river and groundwater contamination from DDT or PCBs, for example, have provided the first case-studies.

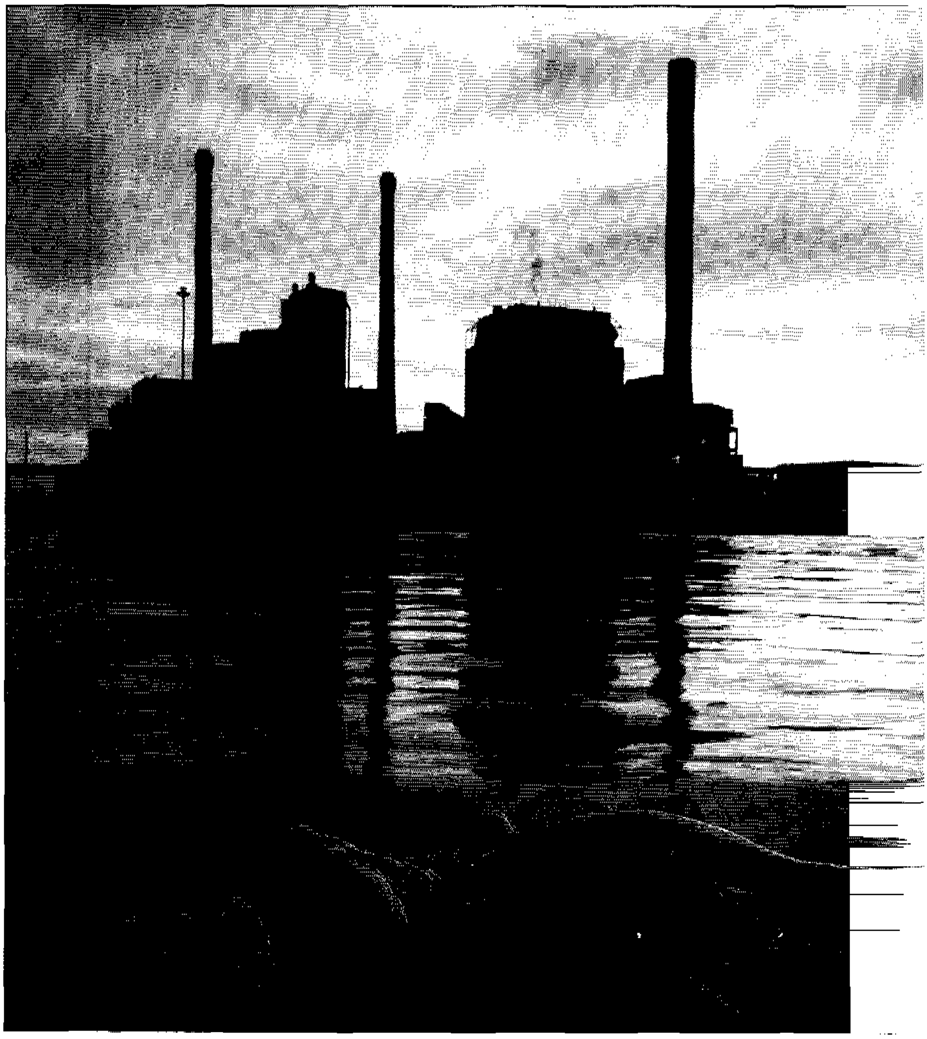
GEMS aims to highlight major trends that could cause tomorrow's global pollution problems, as well as monitoring present levels of contaminants. In line with this, and among the existing water quality issues which require attention, the 1988 assessment suggests that the following current problems need careful examination and further research:

- Accidental pollution is likely to become more serious and more frequent as more industries are built on river banks and long-distance transport by water of the resulting solid and liquid waste increases. The lack of regulations governing how such industries operate and dispose of their waste is cause for concern, particularly in rapidly industrializing countries. As with any sort of disaster relief, response time and coordination are the two most important factors when dealing with a water pollution accident. Thus, water quality management authorities, with the necessary standard procedures for mopping up and containing spills need to be in place to minimize the damage when accidents occur.
- Landfills and mine tailings, which often date back to a time before anti-pollution regulations were introduced, are a hazardous source of water pollution, and will become increasingly significant as other sources of pollution are brought under control.
- Disinfecting water supplies with chlorine sometimes causes the formation of halogenated organics—known to be carcinogenic—and other toxic compounds. The possible long-term health risks need to be assessed.
- Large-scale human activities—including urbanization, industry and agriculture—have started to interfere with natural hydrogeochemical cycles, and are affecting resources beyond single watersheds.

Some of the relevant issues for future global water quality assessments are:

- *pollution from fossil-fuel burning*, causing acidified lakes and contaminated surface waters, even in remote areas;
- *increasing strain on water supplies* as more is used (this is especially serious when coastal aquifers are overdrawn, leading to widespread salinity);

Dead fish in a river in an industrial area of Stockholm. Accidental pollution is likely to become more serious and more common as more industries are built on river banks.



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the impact of deforestation on river basins, such as the Amazon, where deforestation causes the erosion of irreplaceable topsoil and severe nutrient losses;

river damming, which decreases sediment loads, depriving downstream irrigation areas and estuarine fisheries of the nutrients they carry; and

wetland destruction, which destroys many hectares of natural filter mechanism each year, allowing many common pollutants to reach our water supplies.

The future for GEMS/Water

The first assessment has been valuable in highlighting some of the world's major water pollution problems and has also indicated shortcomings in global freshwater-quality monitoring.

Information used for the GEMS assessment was derived from government-run and independent research surveillance programmes in the participating countries. Unfortunately, different methods and instruments are often used in these programmes, making data comparability a difficult issue.

At present, the behaviour, persistence and fate of two of the pollutant groups—metals and organic micropollutants are inadequately researched. Such knowledge is clearly an essential part of understanding their effects on the environment and human health.

Because heavy metals and organic micropollutants are more difficult to sample, prepare and analyse in a dissolved form, future monitoring will probably involve using particulate matter for preliminary surveys and routine monitoring. In addition, sampling methods will need to be improved to eradicate the possibility of contamination from secondary sources, such as the water containers, pumps and filtration units used.

Geographically, the largest gaps in data were the Soviet Union and most of Eastern Europe; almost all of Africa; and parts of Latin America and South-east Asia. Although most of these areas have some sort of monitoring programme in place, the problem is lack of cohesive data collection, processing and evaluation.

Most developing countries have neither the specialized laboratory equipment nor the highly-trained personnel to monitor micropollutant pollution to the same degree as developed countries. Such countries will be encouraged to focus instead upon measuring the simpler categories of pollutant, such as dissolved oxygen and specific ion conductivity, using appropriate methods.

For GEMS/Water specifically, a revised network with more focused objectives and strengthened output is planned. In the decade ahead, the GEMS/Water programme will:

- continue monitoring long-term pollution trends in the world's freshwater resources and determine the loadings of toxic chemicals, nutrients and other pollutants from major river basins to the oceans;
- continue collecting data from trend stations in major river basins to monitor long-term changes in water quality in relation to human activities;
- encompass more major basins and establish more groundwater stations from the mid-1990s;
- encompass river-mouth stations to determine annual fluxes of critical pollutants to oceans and regional seas;
- provide comprehensive global water quality assessments every five years and biennial reports on specific global water quality issues;
- provide data reports as requested by governments, international agencies and regional water authorities;
- review GEMS/Water network data annually and provide yearly trend evaluation reports;
- publish information leaflets to increase public awareness of global freshwater pollution; and
- serve as a centre of expertise for freshwater assessment in relation to sustainable water resource development.

Control strategies

The hazards of freshwater pollution are serious enough for many countries to have taken steps to control sources of contamination. These steps include:

- ☐ regulating sewage disposal;
- ☐ constructing city sewerage schemes;
- ☐ installing waste treatment plants;
- ☐ treating and recycling industrial effluent;
- ☐ substituting harmful consumer products (such as phosphates in washing powder); and
- ☐ banning dangerous pesticides (DDT, for example) and industrial chemicals (such as PCBs).

These steps—although by no means comprehensive solutions—have begun to reduce levels of pollutants in many industrial countries. In the developing countries, far fewer regulations and controls exist, and pollution from domestic wastes is still the cause of widespread death and disease.

The rapidly developing countries of South America and Asia also pose a major threat to water quality because the types of pollution that evolved slowly over a century in Europe are affecting those nations within a decade. Only 10 of the 60 countries in this category have laws in place to deal with these new, environmentally damaging problems.

Action needs to be taken in three main areas: water resource management, wastewater treatment, and providing safe public water supplies.

Water resource management is the long-term solution to water shortages and pollution. International cooperation has already been prompted between countries sharing a river basin. So far the developed countries have been more successful than the developing nations. In Europe, where 4 basins are shared by 4 or more countries, there are 175 treaties to regulate water use; in Africa, however, only 34 treaties regulate the 12 shared basins. Such agreements are clearly essential, particularly when communities downstream receive poor-quality water because of an upstream country's activity. Irrigation in Arizona made the Colorado River so saline by the time it reached Mexico that the Americans, honouring a 1944 treaty, installed a large desalination plant on the border.

The 'polluter pays' concept of cleaning up pollution works in theory, but in practice it is often cheaper for industries to risk paying the occasional fine than to install the necessary waste-control equipment. Seventy of Britain's 111 paper mills polluted rivers or other waterways over an 18-month period in 1989–90 because the fines for doing so are relatively negligible.

In developing countries, dependent on agriculture for survival, more effective means of irrigation must be found if the same land is going to support the greatly increased populations of the year 2000. Surprisingly, the answer does not seem to be more technology and chemicals; research shows that more is to be learnt from ancient means of 'water harvesting' that made use of land levelling, ridges and funnels to channel all available water to where it was most needed. The ancient inhabitants of the Negev Desert used such methods so successfully that they grew enough food for their needs with an average annual rainfall of only 100 mm.

Despite the poor state of much of the world's water, there seems to be a growing realization that even a renewable resource can take only a limited amount of abuse. Perhaps that realization has been helped by news of south-western US cities buying farmers' water rights to meet municipal demand; or by the hose-pipe ban imposed in parts of Britain—renowned for its constant rain; or by the elevated status of bottled water, now that it is not only 'undeveloped' countries that cannot trust what comes out of their taps; or by the use of water as a bargaining chip in Arab-

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Tall chimneys like this one, belching its clouds of black smoke, rich in nitrogen and sulphur oxides, can only aggravate the present problems of acidified freshwater.

Israeli peace; or, indeed, by the sad sight of the Aral Sea, the world's fourth largest freshwater lake, which has shrunk by 18 000 km^3 since 1960 because of excessive withdrawals from the rivers that feed it.

Plans for a large dam in Tasmania were shelved recently after constant protest from pressure groups. Similarly, the Soviets have abandoned ambitious ideas of diverting north-flowing rivers towards the water-scarce south. And when 15 percent of Iowa's rural wells were found to be contaminated with pesticides and too much topsoil was being eroded, US farmers in the Midwest grainbelt were prompted to experiment with less intensive, more environmentally-aware agriculture. Crop rotation, minimum amounts of increasingly expensive chemicals, new planting methods and relaxed cosmetic standards for fruit and vegetables are all reducing the toll on soil and water—and do not necessarily mean reduced yield.

To meet the goal of supplying people with safe water will take more than proposing to cut sewage dumping or sulphur emissions or toxic waste by some relatively insignificant percentage 10 or 20 years from now. Although projected costs to put things right are high, the price of coping with the results of pollution can be equally shocking. For example, Austria will spend an estimated US\$1.3 million/km^2 between 1989 and 1995 to sanitize its eutrophic lakes.

In the meantime, programmes such as GEMS/Water are essential to focus attention on the adequacy in quality and quantity of world water supplies. Results of such assessments, made accessible to the public and policy makers, will alert more people to the pressing need to respect this most valuable of the world's renewable resources.

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