GLOBAL ENVIRONMENT MONITORING SYSTEM

ASSESSMENT OF FRESHWATER QUALITY

UNITED NATIONS
ENVIRONMENT PROGRAMME

WORLD HEALTH
ORGANIZATION

Prepared in co-operation with the Monitoring and Assessment
Research Centre, London

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Report on the results of the WHO/UNEP programme on health-related environmental monitoring

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Preface

Ever since the mid-1970s, the World Health Organization (WHO) in collaboration with the United Nations Environment Programme (UNEP) has, through the Global Environment Monitoring System (GEMS), been operating worldwide networks for monitoring air and water quality and with the Food and Agriculture Organization (FAO) for food contamination, and collecting information on environmental conditions and human exposures in different parts of the world. In 1988 this information, supplemented with other data, was compiled and analysed and for each topic an assessment was made on the global and regional levels and trends. These assessments were considered and endorsed by a government-designated Expert Meeting which was held in Geneva from 12-16 September 1988. Amendments proposed at the Expert Meeting were incorporated in the assessment reports.

The UNEP/WHO Meeting was attended by delegates from 12 countries (Australia, Brazil, Canada, China, Egypt, Ghana, Hungary, India, Japan, The Netherlands, Sudan, U.S.A.) and two international organizations (the Food and Agriculture Organization (FAO) and the World Meteorological Organization (WMO)) and the Monitoring and Assessment Research Centre (MARC). The government-designated Expert Meeting was chaired by Dr. Ahmen Amin El-Gamal, Advisor, Egyptian Environment Agency with Dr. Vic Armstrong, Head, Criteria Section, Environmental Health Directorate, Health and Welfare, Canada, serving as rapporteur. In addition to the review of the assessment reports, the Government Experts also made recommendations concerning the ways in which the monitoring programmes and future assessments might be improved. These recommendations are reflected in the report of the meeting.

This report contains an assessment of freshwater quality worldwide. Similar assessments of urban air quality and food contamination are presented in separate companion documents entitled "Assessment of Urban Air Quality" and Chemical Contamination in Food".

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1 Introduction

Within the framework of UNEP's Global Environmental Monitoring System (GEMS), WHO and UNEP have been collaborating together for the last decade on the world-wide monitoring of water quality. This project, known as GEMS/WATER, forms part of the overall effort of GEMS to monitor the global environment. Other activities in the GEMS health related monitoring programme include the measurement of urban air pollution (GEMS/AIR) and food contamination (GEMS/FOOD). In addition to providing environmental quality data on a global basis, these projects harmonize the methods of measurement among countries and thus improve the quality and comparability of the data generated. Support is also given to the development of national monitoring programmes (UNEP 1987; WHO 1987a).

A considerable data base for the global aquatic environment has evolved from the GEMS/WATER monitoring project since its launch in 1977. The current network consists of a total of 344 stations comprising 240 river stations, 43 lake stations and 61 groundwater stations (Figure 1). While some stations are located in remote areas to obtain background levels of water quality, most are near industrial and urban centres in order to measure the quality of water used, as well as the impact of various pollutants on the quality of water resources. Data collection was started in 1978, and the available data base now covers two triennial reporting periods from 1979 to 1981, and from 1982 to 1984 (WHO 1983a; WHO 1987b). More recent data are taken directly from the GEMS/WATER global data bank held at the Canadian Centre for Inland Waters, Burlington, Ontario where all data are statistically treated and stored.

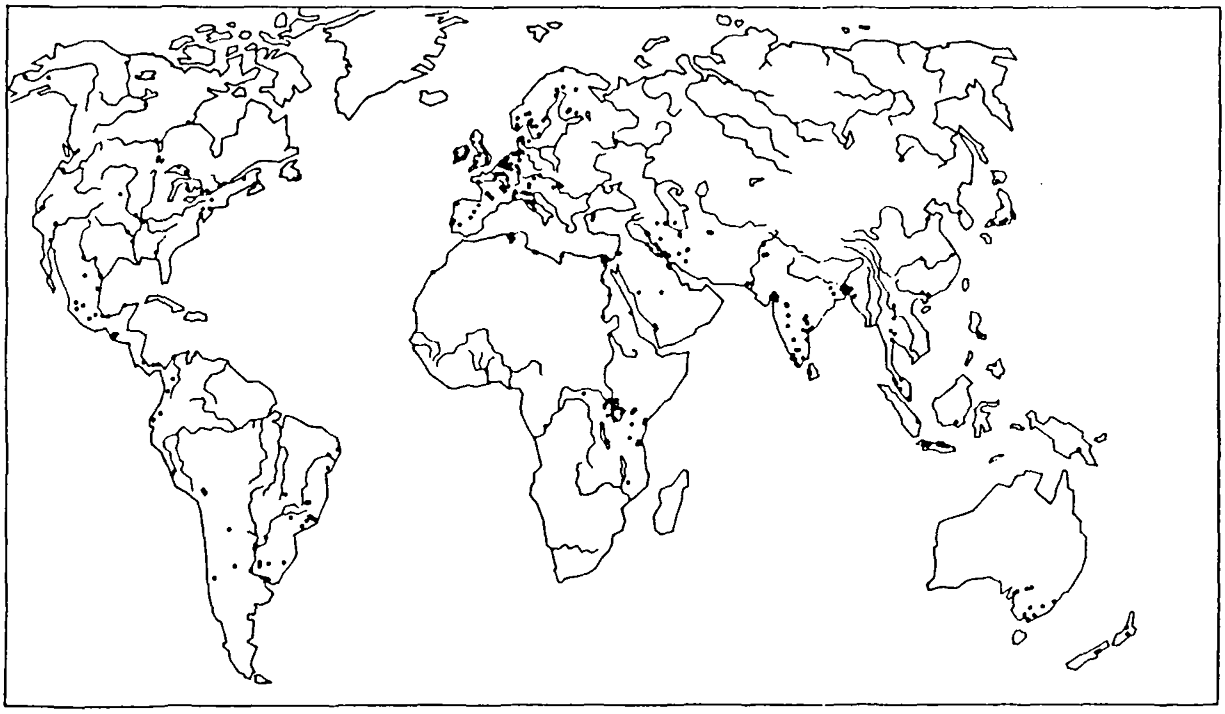

Figure 1 The GEMS/WATER monitoring network

The GEMS/WATER project includes the collection of data for about 50 different indicators of water quality. These include certain basic measurements such as dissolved oxygen, biochemical oxygen demand, faecal coliforms and nitrates, as well as analyses of chemical trace constituents and contaminants (heavy metals and organic micropollutants). The methods used are described in the GEMS/WATER operational manual (WHO 1987a) and participating

Table 1 A list of GEMS/WATER variables

	Rivers	Lakes and Reservoirs	Groundwaters
BASIC VARIABLES			
Temperature	X	X	X
pH	X	X	X
Electrical conductivity	X	X	X
Dissolved oxygen	X	X	X
Nitrate	X	X	X
Nitrite	-	-	X
Ammonia	X	X	X
Calcium	X	X	X
Magnesium	X	X	X
Sodium	X	X	X
Potassium	X	X	X
Chloride	X	X	X
Sulphate	X	X	X
Alkalinity	X	X	X
BOD	X	-	-
Total suspended solids	X	-	-
Chlorophyll a	-	X	-
Transparency	-	X	-
Orthophosphate	X	X	-
Total phosphorus (unfiltered)	X	X	-
Instantaneous discharge	X	-	-
USE-RELATED VARIABLES			
(a) Drinking water supply (1)			
Total coliforms	X	X	X
Faecal coliforms	X	X	X
Arsenic	X	X	X
Cadmium	X	X	X
Chromium	X	X	X
Lead	X	X	X
Mercury	X	X	X
Selenium	X	X	X
Cyanide	X	X	X
Fluoride	X	X	X
Nitrate	X	X	X
TOCl (2)	X	X	X
Dieldrin	X	X	X
Aldrin	X	X	X
DDT	X	X	X
Copper	X	X	X
Iron	X	X	X
Manganese	X	X	X
Zinc	X	X	X
(b) Irrigation			
Sodium	X	X	X
Calcium	X	X	X
Chloride	X	X	X
Boron	X	X	X

Table 1 Continued

	Rivers	Lakes and Reservoirs	Groundwater
(c) General water quality (3)			
Silica, reactive	X	X	-
Kjeldahl nitrogen	X	X	-
COD	X	-	-
TOC	X	-	-
Chlorophyll a	X	X	-
Hydrogen sulfide	-	X	X
Iron	-	X	-
Manganese	-	X	-
PCBs	X	X	X
Aluminium	X	X	-
Sulphate	X	X	-
pH	X	X	-

(1) As in WHO Guidelines for drinking water quality (1982)

(2) Total organochlorine compounds (TOCl), dieldrin, aldrin and DDT are considered as representative of the major categories of organic pollutants listed in the WHO Guidelines

(3) Such as aquatic life support, acidification and eutrophication

countries take part in analytical quality control exercises. Due to the different levels of laboratory services available in countries, there are large variations between countries in the frequency, range and type of measurements of water quality which are regularly made and reported. While most of the participating laboratories measure the basic variables, the number of countries analysing individual chemical substances is much more limited. The variables and measuring frequency prescribed by the project are given in Tables 1 and 2.

Table 2 Recommended annual sampling frequencies for GEMS/WATER stations

	Rivers (2)	Lakes and Reservoirs	Groundwaters
Baseline stations (1)	4 to 12	4	2 to 4
Impact stations			
Drinking water sources	12 to 24	6 to 12	4 to 12
Irrigation sources	12	2	4
Aquatic life	12	6	-
Multiple impact	12	4	4
Trend stations	12 to 24	2 to 6	4

(1) Some baseline stations may be surveyed only every 2 to 5 years according to their accessibility, size of water body and variability of the water quality.

(2) Sampling periods should cover the major seasonal variations of the hydrological cycle; the frequency should be adapted to the hydrological cycle. A maximum sampling is recommended for the smallest watersheds and/or most irregular regimes.

The variables measured by a particular laboratory may also reflect the perceived importance of the variable in question. For example, in many developing countries, microbial pathogens in drinking water are generally of much greater importance than chemical contaminants. However, this situation may not be static in rapidly industrializing countries and efforts should be made to monitor the most appropriate contaminants.

The GEMS/WATER data provide a general, global basis for the present assessment exercise. Limitations, however, exist in two areas:

- some of the important world rivers and lakes are not part of the global network;
- some important water pollutants are measured inadequately or not at all in many situations.

These geographical and analytical gaps necessitate the expansion of the data base for a global assessment beyond the boundaries of the GEMS/WATER network. Other data sets and sources of information were therefore included to establish an adequate overall coverage. Typically, these supplementary sources were national reports of water quality and published results of individual studies.

The objective of this report is to provide an evaluation of global water quality in which special attention is paid to the regional differences revealed by the GEMS/WATER programme. Use is also made of other monitoring networks and programmes to examine temporal trends in water quality and major issues are highlighted. The report also describes the range of strategies available for the control of water pollution and illustrates the consequences of different approaches to pollution problems.

This report was prepared in close collaboration with the Monitoring and Assessment Research Centre (MARC) in London. The following persons were specifically involved in the preparation of this report:

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2 Global Water Resources

Before any meaningful assessment of the quality of world water resources can be undertaken, a variety of aspects have to be clarified. Although the quality of water can be defined in scientific terms, many of the variables in common usage reflect a conceptual understanding which is based upon the different water users' requirements. Related demands on water quality span from drinking to renal dialysis and from hydro-electric power production to wetland habitat conservation.

2.1 Availability

The availability of fresh water resources for human use is jointly determined by hydroclimatological features as well as by population densities and their geographical distribution. Historically, populations have developed in relation to agricultural conditions for sustainable food production and corresponding local water resources. During the last few decades, however, demographic developments and migrations from rural to urban areas have led to a growing disparity between the available per capita water quantity and the demand for domestic water supply, industry and irrigation. Many scientists fear that the population-carrying capacity will soon be reached in arid and semi-arid zones and a *water barrier* may prevent any further socio-economic development. An acute shortage of water for irrigation, and thus for locally sustained food supply, would be the first consequence of this problem. Modern techniques for water-saving irrigation, for wastewater reuse and for advanced water treatment, together with rational and effective water management practices, have been successfully applied in several countries proving that such problems can be overcome. Countries with substantial national water resources but high population density fall into this category, together with arid countries having only marginal fresh water resources but also only a sparsely distributed population to sustain. Large seasonal and interannual variation in rainfall or river flow often pose an additional difficulty which requires elaborate structural and managerial measures to maintain a constant water supply in accordance with needs.

The global situation with regard to per capita water availability varies widely, ranging from about 120,000 m^3 a^{-1} in Canada to less than 100 m^3 a^{-1} in Malta (WRI 1987). Figure 2 shows the trends in water availability in relation to population growth for selected countries. Predicted demographic growth until the turn of the century is taken into account to allow the same figure to indicate the trend over the time period 1975 to the year 2000. The diagram clearly illustrates that the situation is becoming critical for those countries with large semi-arid and arid zones. Large cities and industrial centres in water-scarce areas will require costly water transfer and storage schemes in order to sustain their economic growth.

The per capita availability of water provides only a very general measure of the adequacy of existing water resources. The actual water need for different purposes ultimately determines the relative abundance or scarcity of water. According to one global assessment (WRI 1987), out of the 9,000 km^3 of freshwater estimated to be readily available for human use, between 2,600 km^3 and 3,500 km^3 are currently used. A more detailed estimate was recently made by Shiklomanov (1986) for different demographic developments and different phasing of agricultural and industrial growth for each continent in a time series covering the entire century. Table 3 not only predicts a doubling of global water use between 1970 and the year 2000, but also shifts in the share which each continent demands. For example, requirements in North America are predicted to decrease from 22 per cent to 15 per cent, whereas the Asian needs are expected to increase slightly from 59 per cent to 61 per cent during the period 1975 - 2000. There is a large potential for water resource development in Africa although it is likely that water demand in this region of the world will continue to represent only a small proportion of the global

Total water availability per country correlated with population growth from 1975 to 2000. The diagonal lines represent the number of persons to be supplied by one flow unit (1 million m^3 yr^{-1} of water)

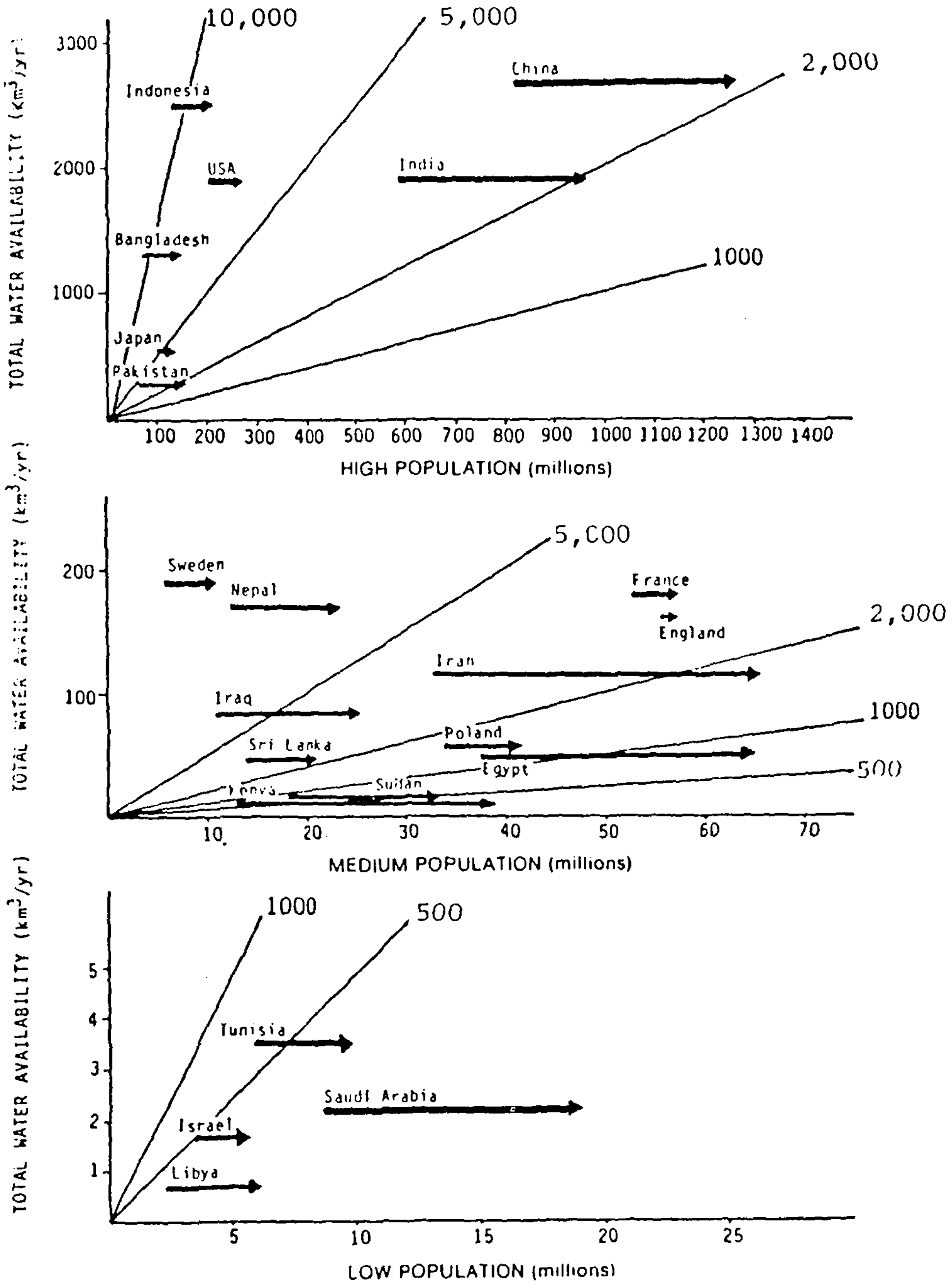


Figure 2 Trends in water availability in relation to population growth

Source : Falkenmark (1986)

total (6 per cent). However, it should be borne in mind that there are large discrepancies between the water-rich river basins and the sub-Saharan drought areas.

Water resources are determined by their hydrological features and their boundaries are naturally confined to drainage areas such as river basins, lake basins or groundwater aquifers. The importance of water resources is variable and linked to man's needs for socio-economic development. Apart from a few modern schemes for inter-basin water transfers, the availability of water within a given basin determines, and often limits, the possibilities for crop production,

Table 3 Trends in water use by continent (km^3 a^{-1})

Continent	Year								% of total
	1900	1940	1950	1960	1970	1980	1990	2000	2000
Europe	37.5	70.9	93.8	185	294	435	554	673	13
Asia	414	682	859	1220	1520	1910	2440	3140	60.5
Africa	41.8	49.2	56.2	86.2	116	168	232	317	6.1
North America	69.4	221	286	411	556	663	724	796	15.3
South America	15.1	27.7	59.4	63.5	85.2	111	150	216	4.2
Australia & Oceania	1.6	6.8	10.4	17.4	23.3	29.4	37.6	46.8	0.9
Total, rounded	579	1060	1360	1990	2590	3320	4130	5190	100

Source: Shiklomanov (1986)

energy generation and expansion of human settlements. Cultural developments have historically been stimulated in large river basins such as the Euphrates/Tigris and the Nile, whereas some cultures have stagnated due to desertification and drought as, for example, in the Sahel zone.

Climatic and hydrological conditions in the various zones and regions around the world have led to a somewhat uneven global distribution of water resources. For the purpose of the present report, water availability in relation to present-day populations is of paramount importance. Per capita river flow of the major world river basins serves as an indicator of the current situation as well as a useful prognostic tool when demographic projections are applied.

A comparison among five continents in Table 4 demonstrates that, for example, South America provides about 10 times more water per inhabitant than Asia or Europe. In Africa, the Congo's per capita availability of water is some 40 times higher than that of the Nile river (Szestay 1982). Severe aggravation of the present imbalances between continents by the year 2000 is predicted, as shown in Table 4. Much less water will be available to the individual inhabitants of Asia and Africa whereas the per capita availability will remain relatively stable in Europe and North America.

In a recent world-wide study broad categories of per capita availability of water were established (WRI 1986). Almost 100 countries were studied and the following conditions found:

Category	**Per capita availability**	**Countries(%)**
Very low	1,000 m^3 a^{-1} or less	14
Low	1,000 - 5,000 m^3 a^{-1}	37
Medium	5,000 - 10,000 m^3 a^{-1}	14
High	10,000 m^3 a^{-1} and more	35

Naturally, availability alone is simply a first indicator of whether abundance or scarcity are more likely. Not all water made available by nature can be used and the actual withdrawals

Table 4 Estimated per capita riverflow in selected river basins of Africa, Asia, Europe and the Americas

Rivers by continents	Drainage area (thousands of sq. km)	Mean annual flow (m³ per sec.)	Population (millions)		Per capita riverflow (m³ per year)	
			1970	2000	1970	2000
Africa	30 300	138 000	350.0	770.0	12 000	5500
Congo	4015	40 000	18.0	41.2	69 000	30 000
Zambezi	1295	7000	5.8	12.0	38 700	18 000
Niger	1114	8100	16.7	40.9	11 200	4600
Sengal	338	700	2.4	5.0	9100	4500
Orange	640	350	4.7	10.9	2300	990
Nile	2880	2800	50.0	106.0	1720	810
Asia	45 000	435 000	2047.0	3800.0	6550	3550
Irrawaddy	430	13 600	20.0	39.6	21 000	10 300
Brahmaputra	935	20 000	51.8	110.4	11 200	5600
Ob-Irtysh	2430	12 000	32.4	42.0	11 100	8800
Mekong	803	11 000	45.6	102.2	7500	3300
Yangtze	1943	22 000	202.0	300.0	3400	2300
Indus	927	5600	70.6	171.7	2450	1050
Ganges	1060	19 000	300.0	585.0	1920	980
Tigris-Euphrates	541	1500	26.3	68.7	1760	680
Hwang-Ho (Yellow)	673	3300	110.0	163.6	930	620
Europe	9800	100 000	645.0	780.0	4800	3950
Rhone	98	1700	7.1	8.7	7400	6030
Po	70	1400	13.4	15.2	3220	2830
Danube	817	6200	75.0	84.6	2540	2260
Rhine	145	2200	39.2	42.8	1710	1580
Vistula	197	1100	19.5	23.9	1700	1410
North America	20 700	191 000	315.0	406.0	19 000	15 000
Yukon	932	5100	0.1	0.2	1 580 000	1 050 000
Mississippi	3222	17 300	56.0	72.2	9600	7500
Colorado	629	580	2.7	3.5	6600	5100
Rio Grande	352	120	5.0	6.5	750	590
South America	17 800	338 000	190.0	400.0	54 500	28 000
Amazon	5578	212 000	4.0	8.9	1 670 000	740 000
Tocantins	907	10 000	2.2	4.9	145 000	65 000
Orinoco	881	17 000	4.8	10.0	116 000	53 000
Magdalena	241	7500	18.0	41.9	12 800	5500
San Francisco	673	2800	12.5	27.9	7000	3100
Parana	2305	14 900	61.0	110.3	6800	4200

Source: Szestay (1982)

will depend upon upstream-downstream relations as well as upon water needs determined by socio-economic development. Only a detailed analysis of the various water users and their quantity and quality requirements will finally enable an assessment of the adequacy and/or deficiency of the available water resources.

2.2 Uses and Requirements

Before discussing the relative importance of different water uses, a systematic review of the various types of water use is necessary. A broad distinction has to be made between uses based upon the withdrawal of water from the resource and uses which take place within the water body.

Table 5 lists all the major water uses and their effects on water quality. It should be noted that there are vast differences in the quantities required for each use, that their impact on the hydrological cycle varies and that they are accompanied by divergent quality requirements. Furthermore, their global distribution is grossly uneven and seasonal variations often determine the use pattern.

Table 5 Links between water use and water quality

A. USES AFFECTING WATER QUALITY	
(i) Municipal:	sewage discharge, stormwater run-off.
(ii) Agricultural:	manure disposal, use of agro-chemicals, drainage water discharge.
(iii) Industrial:	wastewater effluents, cooling water discharges, acid mine drainage.
B. USES AFFECTED BY WATER QUALITY	
(i) Municipal:	drinking, domestic uses, public uses.
(ii) Agricultural:	domestic farm supply, livestock watering, irrigation.
(iii) Industrial:	boiler feeding, cooling, processing, mining.
(iv) Recreational:	water-contact sports (swimming), aesthetic enjoyment.
(v) Aquatic life	aquatic and wildlife, fishing, swamp and wetland habitat, aquaculture.
C. USES NOT LINKED TO WATER QUALITY	
(i) Commercial:	hydropower generation, navigation.
(ii) Recreational:	recreatonal sports, boating.

Quantitative needs for water vary widely among different water uses. On a global scale, needs for irrigation account for about two-thirds of all human uses, as shown in the historical time series in Table 6. The predictions for the year 2000 indicate that:

- the global expansion of irrigated farm land (doubling from 1970 to 2000) will lead, by the turn of the century, to water needs for irrigation alone equivalent to the total world water use in 1980;
- the industrial water needs, mainly due to internal recycling and water-conscious technologies, will grow at a slower pace than domestic water consumption.

It should be noted, however, that many irrigation activities have associated water losses, estimated to be between 50 per cent and 80 per cent, thus offering a considerable potential for technological improvement and substantial water savings (WRI 1987; Shiklomanov 1986). Also the potential for reuse of municipal wastewater in arid and semi-arid zones in order to meet some of the irrigation water demands is gradually being realized, although this would not be clearly reflected in the global balance. In addition, there is considerable potential for water reuse

Table 6 Trends in global water use according to human activity (km^3 a^{-1})

Water use	Year								% of total
	1900	1940	1950	1960	1970	1980	1990	2000	2000
Agriculture	525	893	1130	1550	1850	2290	2680	3250	62.6
Industry	37.2	124	178	330	540	710	973	1280	24.7
Municipal needs	16.1	36.3	52	82	130	200	300	441	8.5
Reservoirs	0.3	3.7	6.5	23	66	120	170	220	4.2
Total, rounded	579	1060	1360	1990	2590	3320	4130	5190	100
Irrigated lands (million ha)	47.3	75.8	101	142	173	217	272	347	

Source: Shiklomanov (1986)

Table 7 Sectoral water use in selected countries

		Sectoral use in %			
		Public supply	Industry (processing)	Cooling (power prod.)	Agriculture (irrigation)
AFRICA	Algeria	13	4	0	81
	Ghana	44	3	0	53
	Sudan	2	0	0	98
	Togo	90	0	0	10
	Uganda	43	0	0	57
	Zambia	72	0	0	28
AMERICAS	Canada	13	39	39	10
	USA	10	11	38	41
	Mexico	5	7	0	88
	Venezuela	37	4	0	59
	Peru	7	0	0	93
	Argentina	9	8	10	73
ASIA	India	3	1	3	93
	Indonesia	95	5	0	0
	Japan	17	33	0	50
	Kuwait	35	4	0	61
	Turkey	7	2	7	85
OCEANIA	New Zealand	52	11	23	14
EUROPE	Germany, Fed. Rep.	10	35	55	0
	Netherlands	5	24	40	32
	Spain	7	5	17	72
	U.K.	23	41	35	1
	USSR	8	15	14	63
	Yugoslavia	16	38	39	7

Sources: OECD (1985b), WRI (1986)

within industry (chemicals, pulp and paper, petroleum and coal, primary metals, food processing) which could further reduce the share of water resources demanded by industry.

Depending on the specific climatic and hydrological situation and the level of socio-economic development, the relative withdrawal rates for different uses are of varying significance. In countries with abundant water resources, the per capita withdrawal rates constitute only a small fraction of the available water. In water-scarce regions, such as North Africa and the Arabian peninsula, most of the available water is used and water is a limiting factor of agricultural development.

It is estimated that a critical level of exploitation of water resources is reached if more than one third of the annual per capita available water is utilized (WRI 1986). In 19 per cent of the countries surveyed, this critical level has been reached and, in some cases, surpassed. The other crucial factor, the socio-economic development pattern, is reflected in the allocations made to each of the major uses in the country. Table 7 is a summary of a recent study which demonstrates the correlation between climate and irrigation water needs, as well as the high percentages of sectoral use for various industrial purposes in certain developed countries. Total needs for public water supply are not determined by the per capita consumption alone which varies widely among countries and urban/rural areas. As a result, total annual water withdrawal varies even among OECD countries from about 200 to 2,000 m^3 per capita (OECD 1985a). Unfavourable or even adverse climatic conditions render water availability a severely limiting factor of economic growth in many developing countries. As a result, the quality of water used for designated purposes is often compromised in order to cope with water shortages.

Water needs by various users cannot be assessed in quantitative terms alone. Water quality considerations are of equal importance, due to the large variety in water quality criteria set by different users. Moreover, wastewaters discharged after use vary greatly in their degree of contamination. Often one use (e.g., industry) renders the waters receiving their inputs unfit for other uses (e.g., municipal supply). With the increases in industrial water use, as indicated in Table 6, the potential for water pollution increases unless effective effluent treatment and other control measures are implemented. Thus, the same increase in, for example, industrial or municipal water use may lead to quite different impacts on the quality of water courses receiving their effluents depending on the level of pollution control applied.

2.3 Trends in water use and reuse

Depending on the status of industrialization and agricultural practices, shifts in the pattern of water use are noticeable in many developing countries. In the more rural countries irrigation is frequently the crucial factor determining the progress in crop production. It is estimated that globally about 3×10^{12} m^3 of water is withdrawn from surface and groundwater resources, out of which only 1.3×10^{12} m^3 actually reaches the crops, i.e., losses account for about half of the water abstracted. Improvement in the handling of irrigation water is therefore considered to be the most important task for the future (Biswas 1983). Exploration and exploitation of new water resources for irrigation is only sensible, therefore, if existing storage and distribution systems are properly maintained and skillfully operated in order to minimize losses.

In developing countries undergoing moderate to rapid industrialization, competition between users for water resources with limited availability becomes a predominant factor in water resource management. Projected water demands for the year 2000 have shown that the total national water resources in many countries situated in arid and semi-arid zones will not be enough to satisfy these demands. Maintenance of the planned pace of economic progress inevitably necessitates that water be reused, either by passing from one user to the next or by recycling within one sector, as occurs in many industrial manufacturing plants. In developing countries treated domestic/municipal wastewaters are commonly reused for agricultural irrigation (Shuval 1987).

Three case studies are presented below which demonstrate the need and plans for wastewater reuse. In Jordan, rapid increases in the industrial and the agricultural sectors are projected as shown in Figure 3. Irrigation demands about 70 per cent of all water which can no longer be provided by available resources. On the other hand, the 30 per cent used by municipalities and industries produce wastewaters which, subject to adequate treatment, could be a valuable source of irrigation water. It is planned that by the year 2000 about two-thirds of the population will be served by sewage treatment plants producing 60 x 10^6 m^3 of reusable wastewater per year. Thus 10 per cent of all irrigation demands could be satisfied (Arar 1987).

In Saudi Arabia, irrigation and municipal water supplies are forecast to be the two predominant water users. Projected demands are given in Figure 4. Limited groundwater resources and negligible surface water and precipitation have led to an early policy decision to reuse all treated municipal wastewaters. It is estimated that of the reclaimed wastewater, about 10 per cent will be used in industry and the remainder in agriculture for irrigation (Arar 1987).

In Mexico, municipal and industrial development plans indicate modest increases in water demand, but the agricultural sector remains the largest water consumer as shown in Figure 5. The most critical part of the country is the Valley of Mexico City which contains about half the country's industry and is one of the largest urban agglomerations in the world. In 1974 the amount of water used in this area was about 1,350 x 10^6 m^3 of which half was used for domestic purposes and one third for industry (Urroz 1982). The present rate of 4 per cent reuse for watering of parks is planned to be increased to 17 per cent of all wastewater generated and would thus meet about 12 per cent of water demands (Postel 1986).

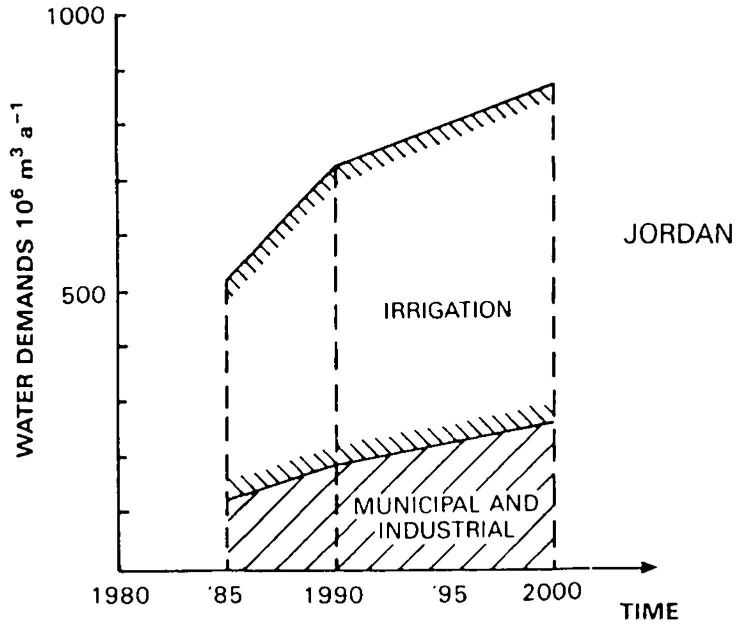


Figure 3 Water demands in Jordan

Source: Arar (1987)

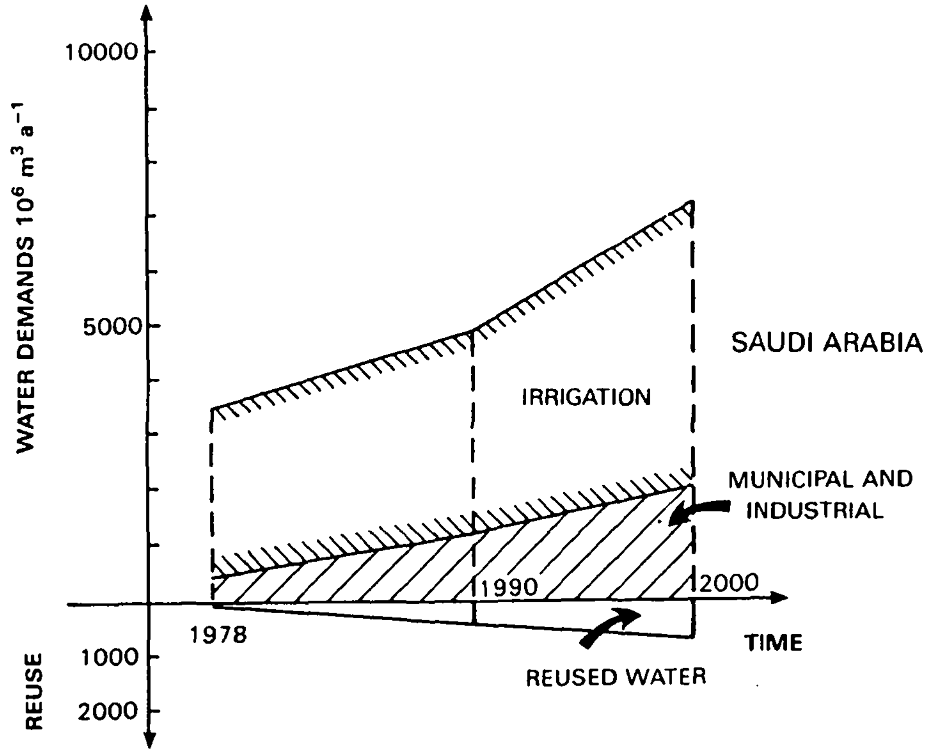


Figure 4 Water demand and reuse in Saudi Arabia

Source: Arar (1987)

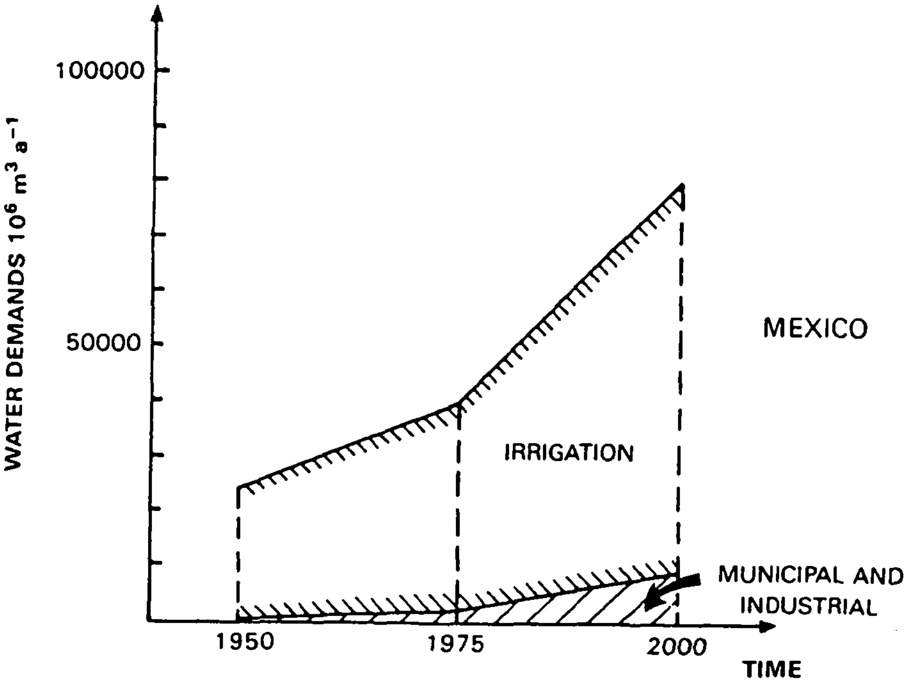


Figure 5 Water demands in Mexico

Source: Urroz (1982)

The three cases described above have in common a planned reuse rate in the order of about 10 per cent. The actual potential for reuse in mixed economies with strong reliance on agriculture may, however, be in the region of 25 per cent. In Israel this target figure has been reached by consistently reusing all waters and, for example, by reverting all sewage discharges to the Mediterranean back to land, mainly for irrigation of crops and farmland (Postel 1986).

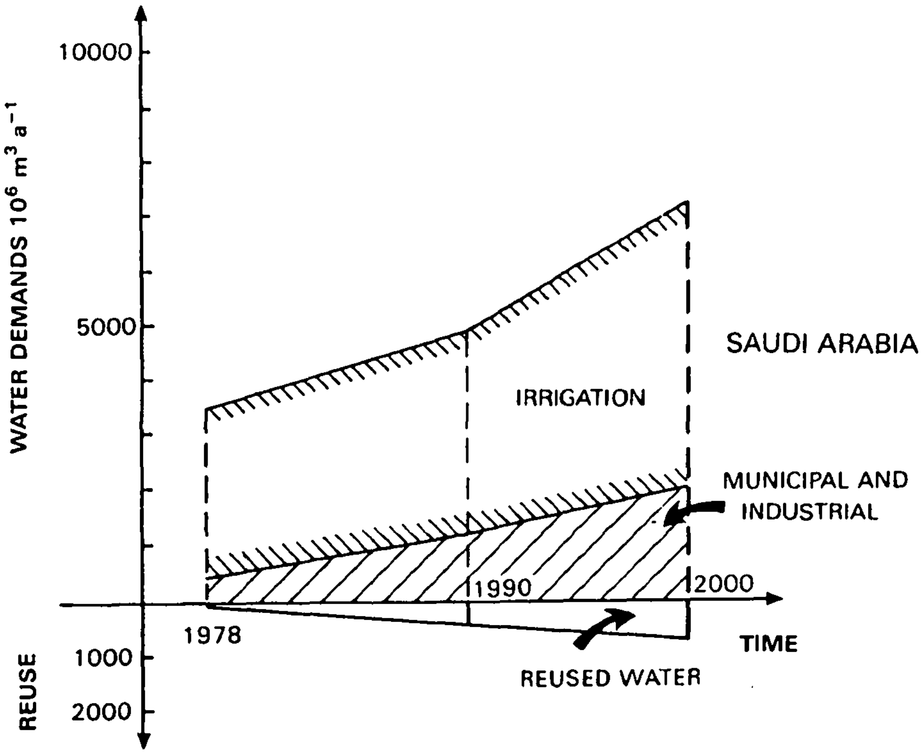
An important secondary effect of wastewater reuse for agriculture is the release of high quality water resources for more demanding purposes such as industrial processing and domestic consumption. In arid countries bordering the sea, desalination of brackish or sea water is also partly used to satisfy demands for these two sectors. Whereas reuse of wastewater is considered for groundwater recharge only after extensive multi-stage treatment, it is not yet an option for augmenting domestic supplies. In industry, on the contrary, great progress is under way in recycling water in the production process as shown in Table 8 for the U.S.A.

Table 8 Water recycling rates in manufacturing industries in the U.S.A.

	1968	1985	2000
Paper and allied products	2.9	6.6	11.8
Chemicals and allied products	2.1	13.2	28.0
Petroleum and coal products	5.1	18.3	32.7
Primary metal industries	1.6	6.0	12.3

Source: Postel (1986)

The increased use of recycling in some countries has led to a large reduction in industrial water demands in spite of increasing output figures. As a result, the relative use of ground and surface waters is changing in the industrialized countries of the Northern Hemisphere. The OECD reports substantial increases in groundwater use in Canada, Portugal and Turkey and significant decreases in Finland, The Netherlands and the United Kingdom (OECD 1985a). Less industrial abstraction of groundwater from wells is certainly responsible for this latter trend.



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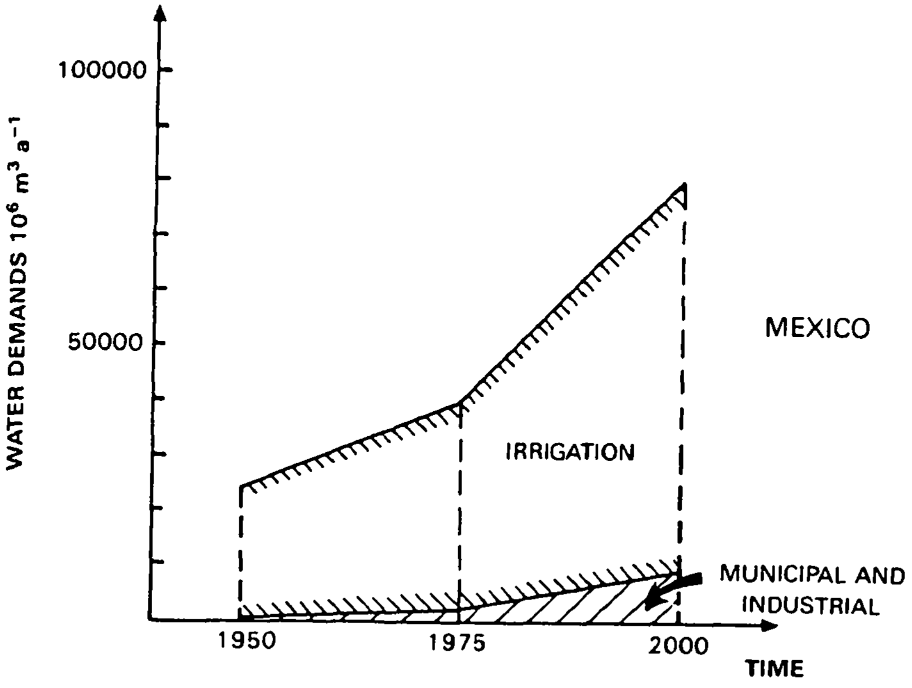

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3 Water Quality

3.1 The History of Water Quality Problems

Over the past decades, the natural quality of water courses has been altered by the impact of various human activities and water uses. Most pollution situations have evolved gradually over time until they eventually became apparent and measurable. Recognition of a pollution problem has therefore usually taken considerable time, and application of the necessary control measures has taken even longer.

Medieval reports and complaints about inadequate excreta disposal, foul and stinking water courses within overcrowded cities and other similar problems were an early manifestation of water pollution. The first time that a clear causal linkage between bad water quality and human health effects was established was in 1854 when John Snow traced the outbreak of cholera epidemics in London to the Thames river water which was grossly polluted with raw sewage. The problem of faecal pathogens in water courses used for public water supply was resolved several decades later. This was due not so much to orderly disposal of municipal sewage, but rather to the invention of sand filtration and its large-scale application since the 19th Century followed by the chlorination of city water supplies since the early 20th Century. As a consequence, waterborne disease outbreaks have become an exceptional event in all industrialized countries and are mostly limited to gross negligence or technical failure. They otherwise occur in small rural supplies which are inadequately treated. Thus the history of pathogens in European waters is a classical example of the appearance, recognition and control of a water pollution problem. The high levels of pathogens still found in European rivers, although a sign of considerable effluent discharges, no longer present a problem for public water supplies. In contrast, the impact of faecal contamination of water resources is the most crucial water quality issue in developing countries.

Since the middle of the 20th Century, and concurrent with the onset of accelerated industrial growth, several water pollution problems have become apparent in rapid succession. Figure 6 illustrates the types of problems as they became apparent in European freshwaters.

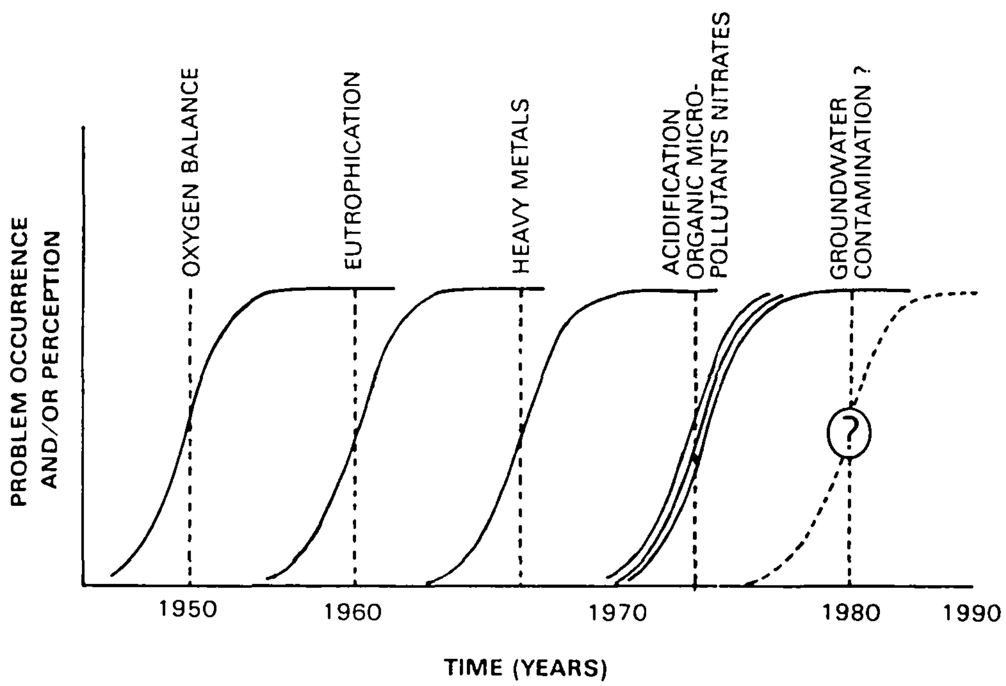


Figure 6 Consecutive occurrence and perception of major water pollution problems in Europe

During the 1950s severe seasonal depletion of the oxygen levels in major European rivers caused a general degradation of their quality and increased difficulties in drinking water treatment. Overloading with biodegradable organic wastes from riparian municipalities and industries was mainly to blame. Costly programmes for mechanical or biological treatment of all major effluent discharges gradually reversed the situation. As a result, the majority of river stretches in Europe today enjoy sufficient oxygen levels to support a variety of fish and provide an acceptable basic water quality for drinking water production.

During the 1960s it became apparent that removal of organic matter from sewage effluents eliminated the primary oxygen demand for biodegradation but did not prevent the secondary effect of algal blooms in lakes and reservoirs. These were stimulated by the presence of high levels of the nutrients phosphorus and nitrogen in the wastewater effluent. Reduction of one of these essential nutrients, phosphorus, was generally adopted as the most effective strategy in the control of the increasing problem of eutrophication. The resulting improvements in many European lakes and reservoirs have, however, been slow.

During the 1970s the increase in heavy metal concentrations in sediments and in the water of rivers and lakes reached worrying proportions. Bioaccumulation in fish and the resulting health risks from consumption of contaminated fish, particularly consumption of coastal fish, resulted in sufficient public concern to bring about legislation for the control of heavy metal releases at source. As a consequence, in the last few years there have been downward trends in the emissions of the most harmful metals such as mercury and lead.

The presence of certain nitrogen compounds in water bodies has traditionally indicated sewage pollution. However, during the early 1980s the levels of nitrate in ground and surface waters approached and, in many instances, exceeded the concentration limits considered safe for human consumption. Excessive widespread application of nitrogenous fertilizers and manure spraying to agricultural land were identified as the main sources. Control measures are currently underway in many countries and their beneficial effect on water quality should become measurable during the coming decades.

During the 1970s scientific and public concerns over environmental pollution entered a second phase. The current production and use of tens of thousands of synthetic chemicals, with about a thousand new ones added every year, has resulted in the release of these substances into the general environment. Today their presence is widespread in ground and surface waters of vital importance for public supply. The human health and ecotoxicological consequences of exposure to organic micropollutants in the aquatic environment are being studied intensively. The search for appropriate strategies for their control, elimination and containment are a major challenge for the next decade.

Also during the 1970s the effects of long-range atmospheric transport of gaseous emissions from the burning of fossil fuels became apparent in the form of acid deposition. Acidification of lakes was the first measurable consequence, followed by the first stages of acidification of rivers and fears of potential spread to groundwaters. The size of the pollution sources has reached proportions which, for the first time, have led to interference with hydrogeochemical cycles. Thus new problems have emerged which are being intensely researched and for which the appropriate global strategies have yet to be determined (Stumm 1986).

It can be seen, therefore, that within Europe the problems of the past (pathogens, oxygen balance, eutrophication, heavy metals) have been recognized, researched and the necessary controls identified and to some extent implemented. However, the present problems are different and often more difficult to combat. Such problems include non-point source pollution by nitrates, ubiquitous environmental contamination by, for example, synthetic organics and problems such as acidification which interfere with global cycles.

The European example was chosen to demonstrate the sequential occurrence of pollution situations along with demographic, industrial and agricultural development. Increases in public awareness, political will and technological progress have allowed control strategies to be developed and implemented. The effectiveness of problem reduction achieved as a direct function of the degree of control introduced, i.e., of economic commitment made, can be demonstrated by the example of domestic sewage pollution. As shown in Figure 7, four phases of problem evolution can be identified in relation to the progress in socio-economic development:

- Phase I: a linear increase in low-level pollution with population (typical pattern for agricultural society);
- Phase II: exponential pollution increase with industrial production, energy consumption and agricultural intensification (typical pattern for moderate to rapidly developing countries);
- Phase III: containment of pollution problems due to the implementation of control strategies (typical pattern for highly industrialized countries);
- Phase IV: reduction of pollution problems, principally at the source, to a level which is ecologically tolerable and does not interfere with water uses (desired ultimate situation).

This general sequence of phases is applicable not only to different types of pollution problems, but also to countries at different levels of socio-economic development. A simplified global scheme with three categories can be used for this purpose as follows:

- highly industrialized countries
- moderate to rapidly developing countries
- low-development countries with predominantly traditional agricultural economies.

For each of these three categories the occurrence and control of the domestic sewage pollution problem follows a different time schedule, as indicated in Figure 7. The extent to which environmental management services have been installed and by how far they are commensurate with the pollution problems largely determine the resulting state of the quality of a country's water resources. Furthermore, different types of pollution problems now occur in developing countries in much more rapid succession than they did in Europe, due to the modern international trade of chemicals, the ubiquitous dispersion of persistent contaminants and changing hydrogeological cycles. Thus developing countries are, and will be, faced increasingly with situations where more advanced pollution issues appear before control over traditional pollution sources has been successfully achieved.

3.2 Water Quality Criteria

The use of water resources is not only determined by the quantity needed for given purposes, but also by the requirements for a certain quality of the water. Such quality is generally described through a set of variables relating to the physico-chemical and biological properties of the water. These variables have evolved over time and are constantly being modified and further refined in line with the expanding uses to which water is put and with the development of analytical capabilities to measure a greater number of substances at ever smaller concentrations. Consequently, the need for water to fulfil more quality requirements has also continued to rise.

Various groups of water users have, to some extent, developed their own approaches and methods for describing and measuring water quality. For the purpose of human consumption and

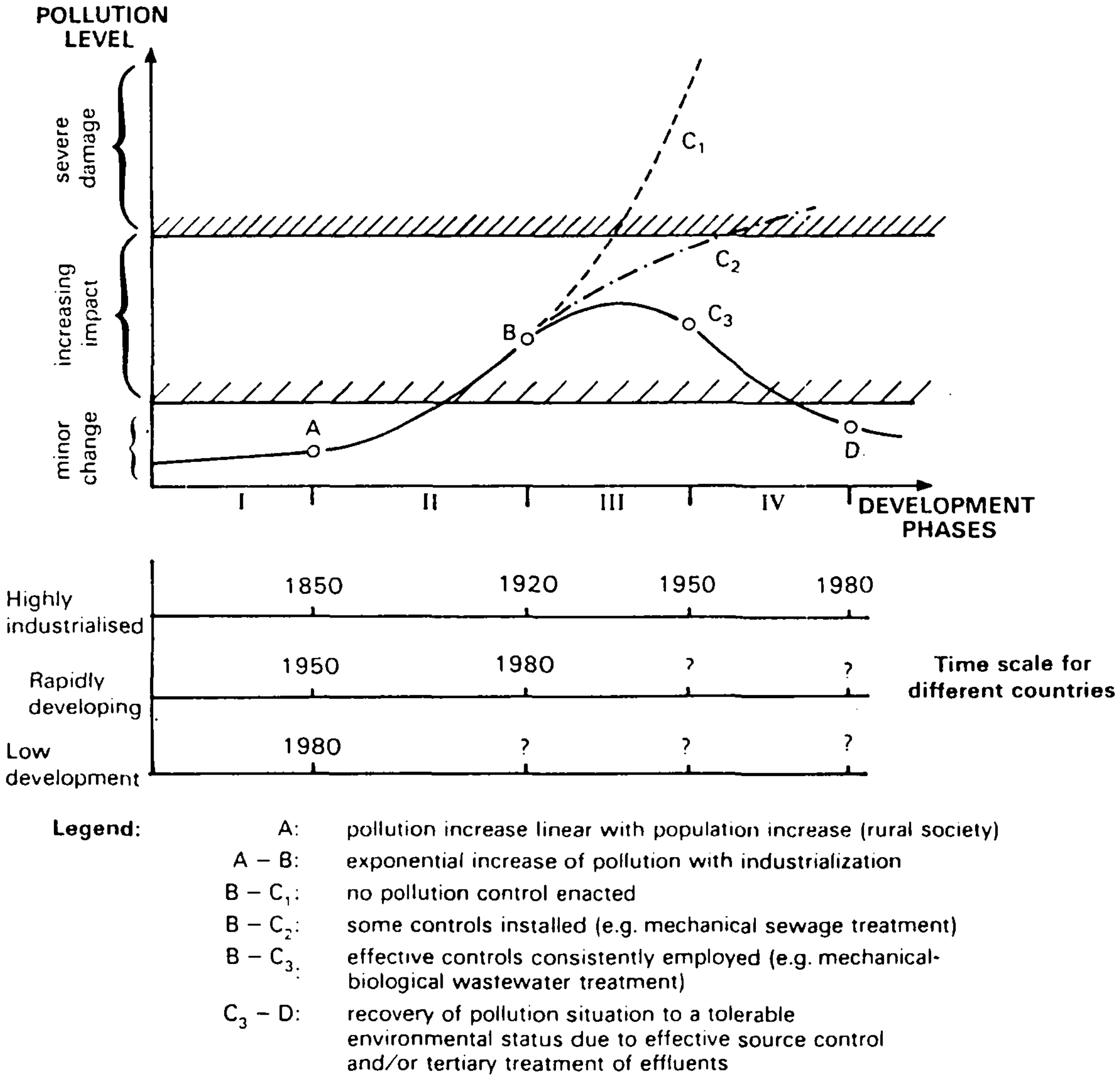


Figure 7 Conceptual model of pollution occurrence and control using domestic sewage pollution in Europe as an example

public water supplies, a set of microbiological indicator organisms has been identified and is now commonly applied to determine the hygienic suitability of water for drinking. The agricultural sector, however, has developed a specific composite ionic variable, the SAR (sodium absorption ratio), which is used to predict the permeability and infiltration rate into soil. River basin management and water pollution control practices have relied for many decades on summary variables, such as the biological oxygen demand and chemical oxygen demand to quantify sewage discharges and the subsequent biodegradation processes in the river. The presence of particulate matter in suspension further complicates the situation and can alter the concentration and behaviour of pollutants and microbes considerably.

Chemical substances in water, either natural or introduced by man, are not only characterized by their concentration and chemical speciation, but also by their persistence in the aquatic environment. Some substances such as chloride or organochlorine pesticides are conservative, others such as heavy metals are affected by physico-chemical processes (e.g., flocculation and precipitation) and substances such as amino acids and detergents are altered by biochemical degradation processes. Bioavailability and effects on aquatic biota (toxic or beneficial) are additional factors that need to be considered for some substances, such as the nutrients phosphorus and nitrogen.

Based upon practical considerations of water use requirements, pollution problems and health effects, water quality variables are grouped for the purpose of this report into the following broad categories:

- microbiological indicator organisms (related to human health)
- particulate matter (with regard to surface waters and their uses)
- indicators of organic pollution (related to surface waters and their uses)
- nutrients (key factors for aquatic life and various uses)
- salinity and specific major ions (an essential factor in determining the suitability of a water resource for most uses)
- inorganic micropollutants (with adverse effects on all non-industrial uses)
- organic micropollutants (with adverse effects on humans and aquatic life)
- acidity (impact of acid precipitation on surface and ground waters)
- nitrate (related to human health)

Guideline values for various use categories are summarized in Table 9. Industrial uses are omitted due to the large variety of quality requirements for different applications. Wildlife and fish are only indicated qualitatively since inter-species variations are considerable. Table 9 also indicates those variables which are monitored in rivers, lakes, reservoirs and groundwaters in the GEMS/WATER project.

3.3 Water Quality Requirements

The relative importance of the different water quality variables listed in Table 9 varies greatly among water user categories. Six principle water uses can be identified together with their major water quality requirements.

Drinking Water

Microbiological aspects and hygienic acceptability are by far the most important requirements related to human consumption and other domestic uses as emphasized by the Guidelines for Drinking Water Quality (WHO 1984a, b). These Guidelines also list a number of inorganic and organic compounds which can affect human health. Excessive concentrations of nitrates and fluorides for example cause methaemoglobinaemia and skeletal fluorosis respectively. Heavy metals, for example mercury and lead, interfere with the central nervous system or upset the human metabolism in various ways. Several of the organic micropollutants listed in Table 9 are known human carcinogens and their presence in drinking water thus increases the risk of tumour formation. Salinity, on the other hand, can be tolerated at much higher levels than indicated by the guideline value. The WHO Guidelines, therefore, make a distinction between substances with health significance and those of more aesthetic/organoleptic importance.

Raw Water Sources for Public Supply

Whereas guideline values have been set for drinking water itself, no firm requirements can be formulated for the source of such water. Treatment processes available today allow for far reaching elimination of undesirable substances, and in many places sea water is desalinated for use as public water supply. For all practical purposes, however, there are limits within which common treatment processes can function properly and produce drinking water in compliance with WHO guideline values. Examples of such treatment-oriented quality criteria for rivers are given

Table 9 Water quality guidelines for various uses (1)

WATER QUALITY VARIABLE	DRINKING WATER	IRRIGATION WATER (2)		LIVESTOCK WATERING	FISHERIES	GEMS/WATER MONITORING
		NO USE RESTRICTION	SEVERE RESTRICTION			
Microbiological Critera						
- Total coliforms (per 100 ml)	0-10					R,L,G
- Fecal coliforms (per 100 ml)	0		<1,000			R,L,G
- Intestinal nematodes (per 1)		<1	<1			
Particulate Matters						
- Total suspended solids (mg l^{-1})						R
- Turbidity (NTU)	1-5				*	
- Transparency (cm)					*	L
Organic Pollution Indicators						
- Diss. oxygen (mg l^{-1})					*	R,L,G
- BOD, COD, TOC					*	R
- Phosphate (mg l^{-1})						R,L
- Chlorophyll a						L
Temperature					*	R,L,G
Nitrogenous Compounds						
- Nitrate-N (mg l^{-1})	10	<5	>30	100		R,L,G
- Nitrite-N (mg l^{-1})				10	*	
- Ammonia-N (mg l^{-1})					*	
- Kjeldahl-N (mg l^{-1})						R,L
Salinity & Specific Ions						
- pH	(6.5-8.5)	6.5-8.4	6.5-8.4		*	R,L,G
- Electrical conductivity Cw (mmho/cm)		<0.7	>3.0			R,L,G
- Total dissolved solids TDS (mg l^{-1})	(1,000)	450	>2,000	1,000-10,000		
- Calcium (mg l^{-1})		SAR <3	SAR >9			R,L,G
- Magnesium (mg l^{-1})						R,L,G
- Sodium (mg l^{-1})	(200)					R,L,G
- Potassium (mg l^{-1})						R,L,G

Table 9 Continued

WATER QUALITY VARIABLE	DRINKING WATER	IRRIGATION WATER		LIVESTOCK WATERING	FISHERIES	GEMS/WATER MONITORING
		NO USE RESTRICTION	SEVERE RESTRICTION			
- Boron (mg l^{-1})		<0.7	>3.0		*	R,L,G
- Fluoride (mg l^{-1})	1.5	1.0	15.0	2.0		R,L,G
- Chloride (mg l^{-1})	(250)	<3	>10		*	R,L,G
- Sulfate (mg l^{-1})	(400)					R,L,G
- Bicarbonate (mg l^{-1})		<1.5	>8.5			R,L,G
- Hardness (mg $CaCO_3$ l^{-1}		(500)				
<u>Inorganic Micropollutants</u> (mg l^{-1})						
- Aluminium	(0.2)	5.0	20.0	5.0	*	R,L
- Arsenic	0.05	0.1	2.0	0.2		R,L,G
- Beryllium		0.1	0.5			
- Cadmium	0.005	0.01	0.05	0.05	*	R,L,G
- Chromium	0.05	0.1	1.0	1.0	*	R,L,G
- Cobalt		0.05	5.0	1.0		
- Copper	(1.0)	0.2	5.0	0.5	*	R,L,G
- Cyanide	0.1					R,L,G
- Hydrogen sulphide						L,G
- Iron	(0.3)	5.0	20.0			R,L,G
- Lead	0.05	5.0	10.0	0.1	*	R,L,G
- Lithium		2.5	2.5			
- Manganese	(0.1)	0.2	10.0			R,L,G
- Mercury	0.001			0.01		R,L,G
- Molybdenum		0.01	0.05			
- Nickel		0.2	2.0		*	
- Selenium	0.01	0.02	0.02	0.05	*	R,L,G
- Vanadium		0.1	1.0	0.1		
- Zinc	(5.0)	2.0	10.0	25.0	*	R,L,G
<u>Organic Micropollutants</u> (ug l^{-1})						
- Benzene	10					
- Carbon tetrachloride	3					
- 1,2-Dichloroethane	10					
- 1,1-Dichloroethylene	0.3					
- Tetrachloroethyelene	10					
- Trichloroethylene	30					
- Pentachlorophenol	10				*	
- 2,4,6-Trichlorophenol	10				*	
- Benzo(a)pyrene	0.01				*	
- Chloroform	30					
- PCBs	-				*	R,L,G

Table 9 Continued

WATER QUALITY VARIABLE	DRINKING WATER	IRRIGATION WATER		LIVESTOCK WATERING	FISHERIES	GEMS/WATER MONITORING
		NO USE RESTRICTION	SEVERE RESTRICTION			
Pesticides (ug l^{-1})						
- Aldrin/Dieldrin	0.03					R,L,G
- Chlordane	0.3					
- 2,4 D	100					
- DDT	1					R,L,G
- Heptachlor	0.1					
- HCB	0.01				*	
- Lindane	3					
- Methoxychlor	30					
- TOCl					*	R,L,G

References:

Ayers and Westcot (1976)
WHO (1983)
WHO (1984a, b)
Engelberg Report (1985)
Hodson (1987)
Kandiah (1987)
Lloyd and Calamari (1987)

Notes:

* = criteria for freshwater fish established
R = variable monitored in rivers
L = variable monitored in lakes and reservoirs
G = variable monitored in groundwaters
SAR = sodium adsorption ratio (based upon Ca, Mg and Na)
( ) = aesthetic (organoleptic) quality requirement for drinking water only
(1) Industrial uses are omitted due to the large variety of quality requirements
(2) Only indicative - highly dependent on plant species

in Table 10. With respect to water use in developing countries, communities are often bound to accept source waters of inferior quality due to a lack of alternative sources or economic and technological constraints to treat the water adequately before distribution to consumers.

Agricultural Uses

Irrigation is by far the biggest water use in all countries in the arid and semi-arid zones and the associated quality requirements are of particular significance for the assessment of water resources. Soil permeability problems are associated with low salinity water or high sodium water. A list of recommended values for different elements is included in Table 9. Limits on salinity vary in accordance with the sensitivity of the crops selected. Specific ion toxicity is the effect of sodium, chloride and boron on sensitive crops. In addition, there are trace elements which affect specific plants (Kandiah 1987).

Farmstead use of water should normally follow the guidelines for drinking water quality. For livestock and poultry, however, waters of higher salinity can also be used. The tolerance of different animals is roughly as follows (Kandiah 1987):

Salinity	**Use Restrictions**
less than 1,000 mg l^{-1}	Excellent source for all livestock and poultry
3,000 - 5,000 mg l^{-1}	Poor waters for poultry and causing problems
7,000 - 10,000 mg l^{-1}	Unfit for poultry and swine, considerable risks for other livestock
more than 10,000 mg l^{-1}	Not recommended under any condition

In addition, there are recommended limits for inorganic micropollutants, similar to those of drinking water for humans.

A special case of rapidly growing future importance is the use of treated waste water in agricultural irrigation (Shuval 1987). In light of the public health implications of related practices, WHO has recently issued guidelines for restricted and unrestricted irrigation which also quantify intestinal nematodes as a water quality variable (Engelberg Report 1985). Epidemiological considerations and health risk assessment are the basis for these criteria.

Table 10 Water quality criteria in river waters used for public supply

WATER QUALITY VARIABLE	High quality water minimal treatment			Low quality water advanced treatment		
	India	Japan	UK	India	Japan	UK
Dissolved oxygen, DO (mg l^{-1})	> 6	> 7.5		> 4	> 5	
(% saturation)			> 80%			> 40%
Biochemical oxygen demand, BOD (mg l^{-1})	< 2	< 1	< 3	< 3	< 3	< 9
Total coliforms (MPN/100 ml)	50	50	-	5,000	5,000	-
Treatment steps required	Disinfection and filtration			Full treatment and disinfection		

Sources: Young (1980); Kubo (1983); Chaudhuri (1985); Fujiwara (1985)

Industrial Uses

Water is used in industry for a variety of purposes ranging from mere cooling to raw material, transport medium, cleansing agent, and as a source of steam for heating and power production. Quality requirements are equally widespread and continuously changing in accordance with technological developments. Cooling water constitutes by far the largest quantitative use, but it also demands the least stringent water quality. Nuclear power stations have become the most dominant users of cooling water.

Industries often use their own supply systems, including pre-treatment as necessary, or take advantage of the public water supply. For certain purposes waste waters can be treated and reused or desalinated sea water may be suitable. Technology and economics determine the choice in any particular case. In principle, almost any water source can be brought up to the quality standards required.

Fisheries and Wildlife

Many of the criteria developed for freshwater fish are based on the work of the European Inland Fisheries Advisory Commission (EIFAC) of the Food and Agriculture Organization (FAO). This group of experts stated that *water quality criteria for freshwater fish should ideally permit all stages in the life cycle to be successfully completed and, in addition, should not produce conditions in a river water which would either taint the flesh of the fish or cause them to avoid a stretch of river where they would otherwise be present, or give rise to accumulation of deleterious substances in fish to such a degree that they are potentially harmful when consumed* (Lloyd and Calamari 1987). The reviews prepared by this group are marked by an asterisk in Table 9. It is difficult to provide numerical guideline values due to the differences in sensitivity of various freshwater fish to environmental conditions. Dissolved oxygen, however, is a common critical factor in any aquatic community. In the absence of any specific data base, arbitrary oxygen limits may be set around 2 mg l^{-1} to safeguard scavenger fish, at least 4 mg l^{-1} for most game fish, and higher values for sensitive game fish and favourable conditions for fish life, growth and reproduction. In addition, there are many inorganic and organic micropollutants which adversely affect fish. Polynuclear aromatic hydrocarbons (PAHs) and chlorinated organics such as PCBs and HCB have led to tumour formation, spinal curvatures and other malformations (Hodson 1987).

Recreational Uses

Although many countries have promulgated bacteriological and other water quality standards for water-contact sports (e.g., swimming), there is only very limited epidemiological evidence available on which rational criteria can be based. Enterococci have been found to correlate well with gastro-intestinal infection of swimmers in coastal waters (Cabelli et al. 1983) and studies in freshwaters have confirmed this (Dufour 1984). Numerical guideline values have been adopted by many countries for bathing waters, for example, the presence of faecal coliforms at 100 organisms per 100 ml for good and 1,000 per 100 ml for acceptable bathing waters. Similar limits also seem appropriate for freshwater swimming. These criteria may at least serve as a general orientation for relevant assessments of rivers or lakes with regard to public access for swimming.

3.4 Health Aspects

Although the main issue of the present global assessment concerns the chemical quality of water resources and their impairment due to pollution and land use, the aquatic environment plays a crucial role in the transmission of human diseases. In absolute numbers, most human suffering and deaths in developing countries are due to water-associated diseases. Inadequate water supply, insanitary excreta disposal and vector-infested water courses are held responsible for more than half of the 6 million infant diarrhoeal mortalities recorded each year in the Third World (WHO 1982).

Natural waters, apart from a few extreme situations, are full of biological life which contributes to maintaining the ecological and the physico-chemical balance of the water body. However, there are several microbiological and biological pathogens which impair human health or can be life-threatening. They act not only through drinking water but also through various pathways of human exposure, including vectors in the aquatic environment.

Water naturally picks up a variety of chemical substances from the earth's crust as it passes through the geohydrological cycle. With the advent of industrialization and growing populations, many more chemicals are added to the water in rivers and lakes or percolate into aquifers. Apart from their contribution to the ionic balance in water, the chemicals may have quite different consequences for human beings. Some elements are beneficial or even an essential part of dietary intake while others are harmful at any concentrations. A few play a dual role, i.e., minimal concentrations are essential while severe health impairment occurs at higher concentrations. Others are of organoleptic concern only, i.e., impairing taste and odour but have no health importance.

Microbiological and Biological Agents

In terms of global assessment, principal distinctions have to be made with regard to the source of the pollution, route of entry into the human body and the life cycle of the pathogen and its eventual vector organism. Although there are various classifications (El Gamal 1987), the one highlighting the role of the aquatic environment may be most useful for the present purpose (McJunkin 1982). Three typical situations can be distinguished, although some diseases may fall under more than one classification:

- **Water-borne diseases** include enteric diseases (diarrhoea, dysentery etc.) due to pathogens in drinking water which are of faecal origin. A variety of bacteria (salmonella, shigella, coli, vibrio, cholera etc.), entero viruses (rotavirus, Polio virus, Norwalk type agents etc.), protozoa *(Entamoeba histolytica)* and helminths (Guinea worm, Hookworm etc.) are aetiologically responsible. High infant mortality is the main consequence, contributing to the numbers given in Table 11.
- **Water-hygiene diseases** are the consequence of inadequate use of water to maintain personal cleanliness. Enteric diseases, eye (trachoma) and skin (scabies) disease as well as louse-borne (typhoid) diseases are the results. Water quantity appears to be of higher priority than quality in this category.
- **Water-habitat diseases** are vector-borne and the most important group of diseases related to the development of surface water resources.

Three different types of vectors are involved in disease transmission:

- **snail vectors** are the essential link in transmitting schistosomiasis. More than 70 countries in the tropics and sub-tropics are affected, and the disease is spreading and intensifying due to new irrigation projects which create a favourable environment for the aquatic host of the disease vector.
- **mosquito vectors** are responsible for the widespread occurrence of malaria, filariasis and arboviruses. The malaria parasite is transmitted by a mosquito which depends on the aquatic environment for breeding. About 1.2 billion people live in areas where malaria is currently endemic.
- **fly vectors** transmit onchocerciasis (river blindness) and trypanosomiasis (sleeping sickness). Highly aerated, running water is the preferred habitat for breeding of the vector (Simulium fly) of onchocerciasis. Parts of South-West Africa and Central America are suffering very badly with blindness rates of up to one third of the adult population in the affected rural areas.

The complexity of interrelations between the disease-causing parasite, the host vector, the aquatic environment and man is shown in simplified form in Figure 8. The resulting morbidity and mortality for the various diseases is estimated globally in Table 11. In terms of control of vector-borne diseases, the role of water-resource development (dam building, reservoir construction, irrigation canals, etc.) cannot be underestimated. The endemic spread of schistosomiasis and of onchocerciasis has been severely influenced by water construction works (Bahar 1987). The building of the first Aswan Dam in 1900 increased the rate of schistosomiasis infection from 6 per cent to 60 per cent within three years from project completion (Rosenfield and Bower 1979). In Sudan and other countries, schistosomiasis was reintroduced by irrigation projects into areas previously free of the disease. In the Volta valley in West Africa, the fly vector of onchocerciasis was drastically diminished by structural changes of the hydraulic flow regime of the river and concurrent spraying of larvicides (e.g., malathion).

Table 11 Morbidity and mortality due to water related diseases in Africa, Asia and Latin America, 1977-1978

Type of disease	Infection	Infections- thousands per year	Deaths- thousands per year	Average no. days lost per case	Relative* disability
Water-borne	Amoebiasis	400,000	30	7-10	3
	Diarrhoeas	3-5,000,000	5-10,000	3-5	2
	Polio	80,000	10-20	3,000+	2
	Typhoid	1,000	25	14-28	2
Water-hygiene	Ascariasis (roundworm)	800,000-1,000,000	20	7-10	3
	Leprosy	12,000	very low	500-3,000	2-3
	Trichuriasis (whipworm)	500,000	low	7-10	3
	Hookworm	7-9,000,000	50-60	100	4
Water-habitat with water-related vectors	Schistosomiasis (bilharzia)	200,000	500-1,000	600-1,000	3-4
	African trypanosomiasis (sleeping sickness)	1,000	5	150	1
	Malaria	800,000	1,200	3-5	2
	Onchocerciasis (river blindness)	30,000	20-50	3,000	1-2

*
1 sufferer is bedridden
2 sufferer is able to function to some extent
3 sufferer is able to work
4 sufferer experiences minor effects

Source: Walsh and Warren (1979)

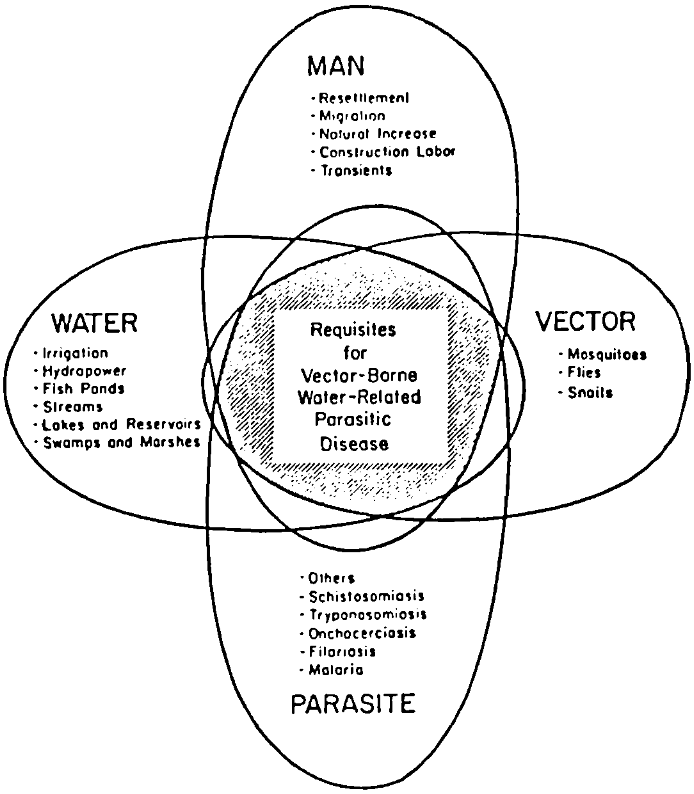


Figure 8 Water habitat and vector-borne diseases
and their relation to the aquatic environment

Source: McJunkin (1975)

With respect to water-borne diseases, only the improvement of the microbiological quality of drinking water together with supporting measures in hygienic education, sanitation and food safety, will bring about substantial reductions of intestinal infections and infant mortality. Rough estimates indicate that the provision of hygienically safe drinking water and related measures could reduce morbidity and mortality due to water-related diseases by half (Hughes 1983). Protection of water sources from pollution is certainly the first measure required. Water treatment is the next barrier against disease transmission, a measure upon which all industrialized countries rely heavily.

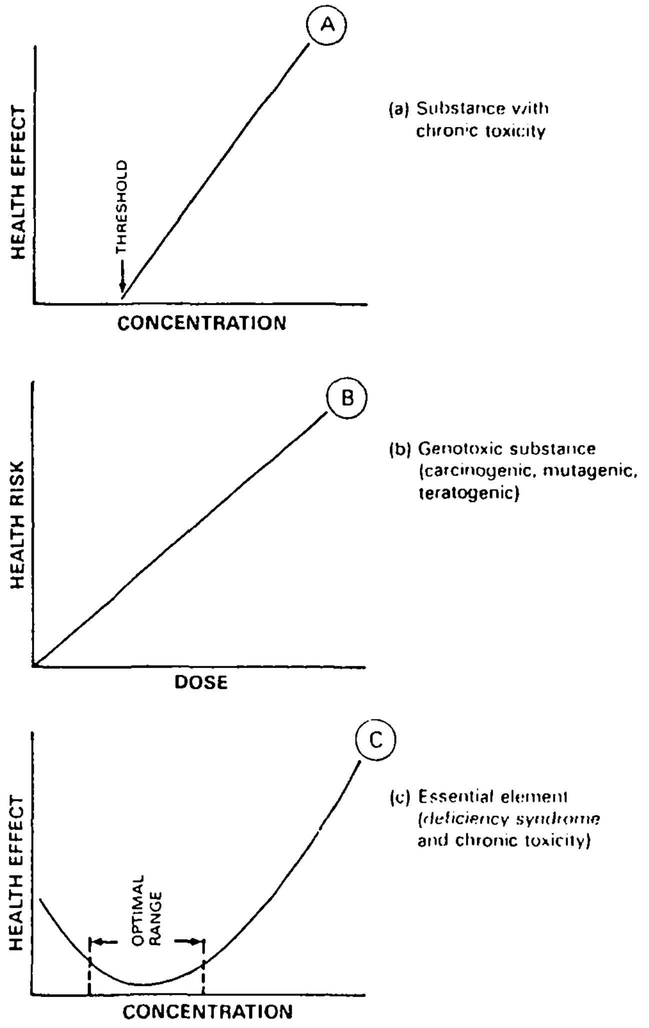
Chemical Constituents and Pollutants

Most chemical substances dissolved in water due to natural processes are essential for the balance of the human body. A minimum content of dissolved substances is vital for human consumption whereas the water becomes unpalatable when they exceed certain concentrations and, at even higher values, they are a health hazard. For the purpose of health impact assessment, chemicals in drinking water may be classified into three categories (Galal-Gorchev 1986):

- substances exerting an acute and/or chronic toxicity upon consumption. The severity of the health impairment increases with the increased concentration in drinking water. On the other hand, below a certain threshold concentration no health effects can be observed (NOEL = no observed effect level) i.e., the human metabolism can tolerate this exposure without measurable long-term effects (Figure 9). Various metals, nitrates and cyanides are within this category.

- genotoxic substances which cause health effects such as carcinogenicity, mutagenicity and birth defects. According to present scientific thinking, there is no threshold level which could be considered safe, since any amount of the substance ingested contributes to an increase in risk. Complex mathematical extrapolation models are used to determine such risks since very little epidemiological evidence exists (Figure 9). Synthetic organics, many chlorinated micro-organics, some pesticides, and arsenic are in this category.
- essential elements are a mandatory part of dietary intake in order to sustain human health. For some elements the contribution made by drinking water is a crucial one (fluoride, iodine, selenium) and, if deficient, cause adverse health effects. At high concentrations, however, these same substances cause equally severe health effects, but of a different nature (fluorides, selenium) (Figure 9).

The above categorization is important for the health-related assessment of chemicals in drinking water because water, although in its natural state, may still affect human health. In addition, many pollutant substances enter the aquatic environment and affect the aquatic ecosystem itself or human health or both. Such substances will be discussed later in the report.



(a) Substance with chronic toxicity

(b) Genotoxic substance (carcinogenic, mutagenic, teratogenic)

(c) Essential element (deficiency syndrome and chronic toxicity)

Figure 9 Health aspects of various types of chemical water constituents

4 Assessment of Water Pollution Sources and Effects

There are pollution problems which have reached global proportions and are now affecting water resources on several continents. Other issues, such as domestic sewage or agricultural run-off, are of importance within each watershed but have nevertheless occurred world-wide. All countries share the resulting problems and many apply similar control strategies and technologies. The current water pollution problems causing most concern are predominantly associated with a specific type of water resource as indicated in Table 12. The following assessment is undertaken according to the dominant pollutant source (activity or process) and the related environmental impact.

Table 12 Occurrence of major pollution problems in different water bodies

Type of water body	Water Pollution Problem	
	Specific to water body	Ubiquitous occurence
Rivers	Pathogens Organic Matter Suspended Matter Acidification	Heavy metals
Lakes and Reservoirs	Eutrophication Acidification	Organic Micropollutants
Ground-waters	Salinization Nitrates	

4.1 Domestic and Other Organic Wastewater

The bulk of polluting matter discarded into water courses world-wide is organic material in the form of domestic sewage, municipal wastes and effluents from the agro-industry. With the shift from simple excreta disposal facilities to sewage collection networks in urban areas, the problem of subsequent water pollution has arisen. Trends in demography and urbanization determine, therefore, to a large extent, the future potential for water pollution within and downstream of urban areas. Such pollution can result in gross deterioration of the receiving water quality.

Problems of this nature are particularly apparent in the developing world where urbanization is reaching serious proportions. While in the 1950s only one city in the developing countries had a population in excess of 4 million, in 1980 there were 16 such cities. It is expected that by the year 2000 there will be 60 such cities in the developing countries. The problems of urbanization stem from the high birth rates in, and the migration into, areas which are generally unprepared for the influx of vast numbers of people. The consequences include severe overloading of major infrastructures, including the over-taxing of existing water supply and sewerage systems. Provision of adequate sanitation lags behind urban growth and the magnitude of this problem is expected to double every 10 years. As a result, very large segments of the urban population are living in unhygienic conditions or slum areas with inadequate access to clean drinking water and sanitation facilities. The situation is aggravated by a tendency to take control measures only after a critical pollution level is reached or exceeded.

Based upon statistics on urban areas obtained during the Water Decade, the world-wide trends in water supply and sanitation are shown in Figure 10. Due to high population growth and the trend towards urbanization, the proportion of urban dwellers with adequate sewerage facilities remained at about 50 per cent in spite of massive investments in this sector. It is hoped, however, that in urban areas this fraction can be raised to between 70 per cent and 80 per cent by the end of the decade. However, installation of sewage treatment facilities is a long-term process as shown for industrialized countries in Figure 11. It is predicted that only a few large urban centres in Africa and Asia will be served by adequate municipal sewerage and wastewater treatment schemes in the near future. In contrast, present coverage and planned expansion of control measures is far more advanced in Latin America.

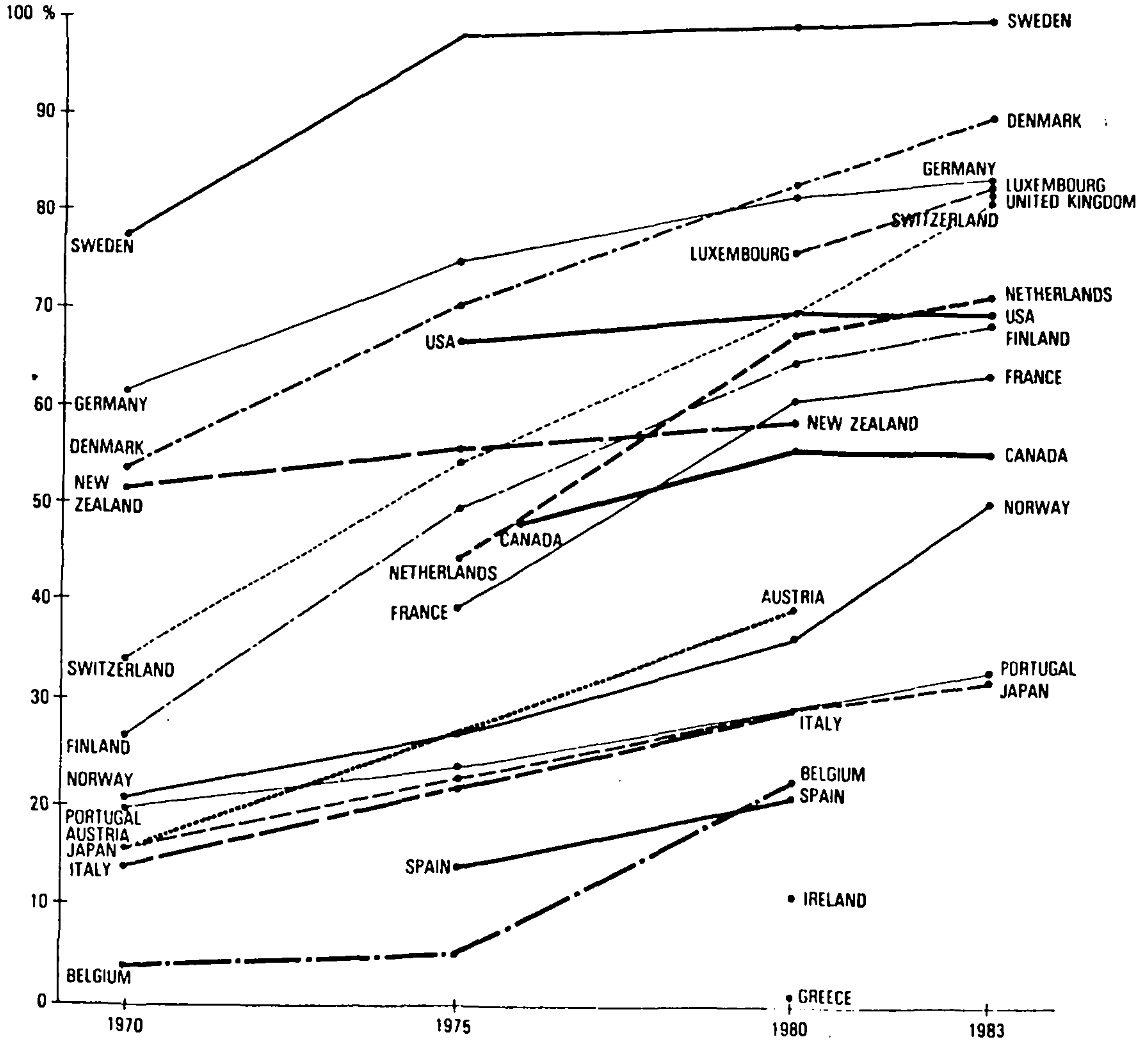


Figure 11 Percentage of population served by wastewater treatment plants, 1970-1983

Source: OECD (1985a)

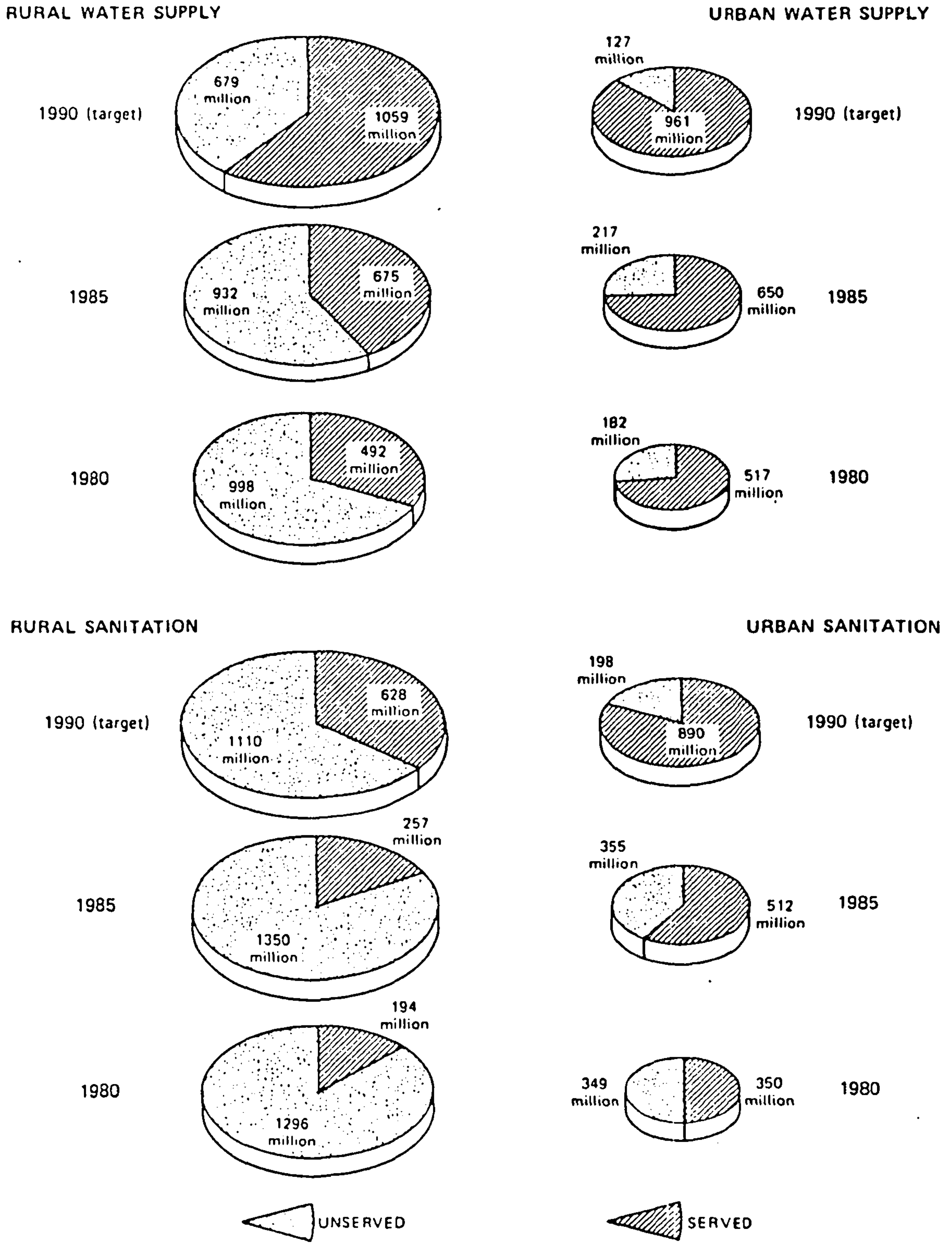


Figure 10 Water supply and sanitation - global levels of service coverage

Source: WHO (1988)

Domestic sewage discharged into water courses affects water quality and, therefore, other water uses through three main polluting agents: (i) pathogens, (ii) organic matter (in suspended or dissolved form) and (iii) nutrients (phosphorus and nitrogenous compounds). Their global significance and related trends are described in the following sub-sections.

4.1.1 Pathogens

Bacteriological contamination of water courses, as measured by indicator organisms, is a common problem throughout all continents wherever urban areas discharge their sewage. Table 13 shows that high population concentrations in Europe, for example in the Rhine river basin, result in large faecal contamination levels despite the substantial sewage treatment practised throughout the region. The influence of urbanization on the long-term trends in total coliform levels is shown in Figure 12 for the River Seine, at Ivry in France. The rate of increase during the post-war period was stabilized by the construction of wastewater treatment plants during the 1970s.

Table 13 Faecal coliforms in GEMS rivers

Number of faecal coliforms per 100 ml	Number of rivers in each region*			
	North America	Central & South America	Europe	Asia and Pacific
	8	0	1	1
10				
	4	1	3	2
100				
	8	10	9	14
1000				
	3	9	11	10
10000				
	0	2	7	2
100000				
	0	2	0	3
Total number of rivers	23	24	31	32

*No data from Africa reported

In terms of health risks, the high coliform counts in European rivers may have little significance since the vast majority of municipal water supplies are treated and disinfected. This is not the case for large parts of Asia and Central and South America. As a result, high coliform counts in these regions are undoubtedly a contributing factor to the high morbidity and mortality rate of infants due to diarrhoea and other symptoms resulting from gastro-intestinal infections. Of India's 3,119 cities only 217 have partial (209) or full (8) sewage treatment facilities. Thus the 48 kilometre stretch of the Jamuna River which flows through New Delhi contains 7,500 coliform organisms per 100 ml water before entering the capital, but after receiving an estimated 200 million litres of untreated sewage every day, it leaves New Delhi carrying 24 million coliform organisms per 100 ml (WRI 1986). Values for Africa are not yet reported under the GEMS/WATER project, but what information is available confirms a similar pattern of bacteriological water quality and disease distribution.

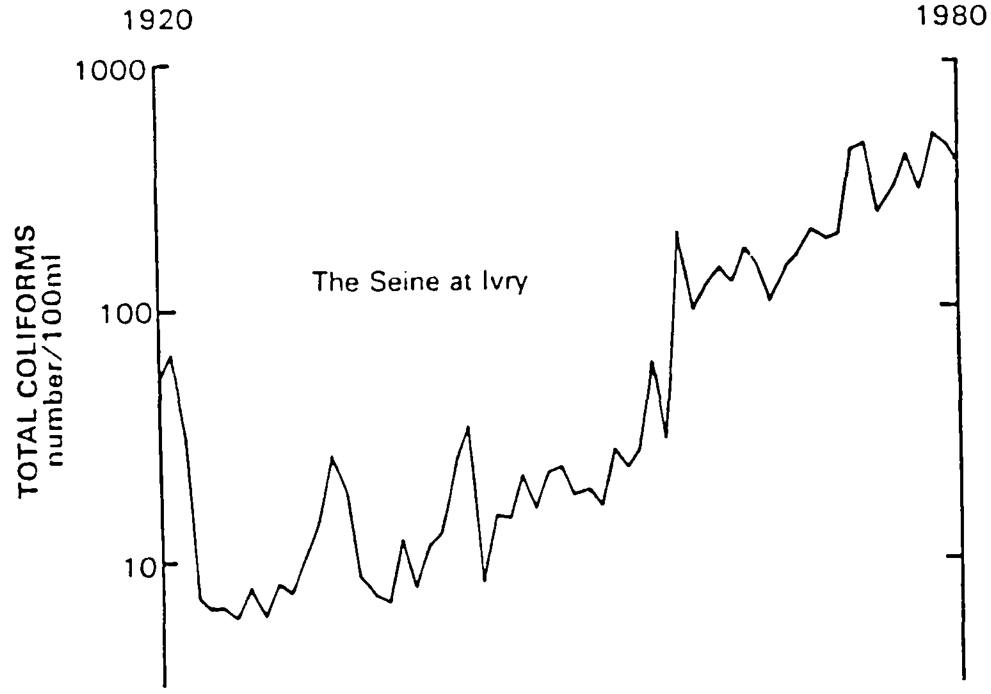


Figure 12 Long-term evolution of pathogen pollution in the River Seine, France

Faecal pollution has also been detected through high counts of coliforms and streptococci in more than two-thirds of the GEMS/WATER groundwater monitoring stations, mainly situated in developing countries. These contrast with the negligible counts recorded at baseline stations remote from human impact (Tables 14 and 15).

4.1.2 Total Organic Matter

The largest amounts of any pollutant group discharged into water courses are organic compounds, either dissolved in effluents or associated with suspended matter. Their most significant characteristic is biodegradability which is measured as biochemical oxygen demand (BOD). Thus oxygen consumption during their decomposition is the single most important impact on the receiving waters. In hot tropical countries where natural oxygen saturation levels in rivers are lower and where biodegradation rates are higher, the discharge of untreated sewage or other organic wastes often leads to severe oxygen depletion.

In the GEMS/WATER programme measurements are made of indicator variables such as the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD). In practice BOD and dissolved oxygen are the most commonly reported water quality variables in the GEMS/WATER network with 72 per cent and 86 per cent of stations reporting these variables respectively. COD is measured at only 48 per cent of stations. The global results, summarized in Table 16, show that around 10 per cent of all rivers may be described as polluted in that they have a BOD of more than 6.5 mg l^{-1} and a COD of more than 44 mg l^{-1}. Furthermore, the oxygen saturation is inadequate (i.e., less than 55 per cent) in about 5 per cent of the sampled rivers. In evaluating the significance of organic river pollution much depends on the use of the downstream river water and any associated water quality requirements.

Table 14 Water quality monitoring data - extracts from baseline stations*

Water source	Country	Water temp°C	pH range	Suspended solids (mgl^{-1})	BOD maximum (mgl^{-1})	Fecal coli 100 ml^{-1}	Fecal strep 100 ml^{-1}	Total coliforms 100 ml^{-1}
1. RIVERS								
Temperate waters (minimum temp. <10°C)								
Glama	Norway	0.0-17.0	6.6-7.7	--	5(TOC)	5-635	--	--
Cark Suyer	Turkey	5.0-25.0	7.0-8.6	1-90	3	240	--	--
Kiso	Japan	2.0-22.0	6.6-7.5	1-39	2	110-2600	17-1600	--
Mapocho	Chile	4.5-18.8	6.5-8.2	4-648	2	2-790	2-540	--
Tropical waters (temp above 10°C)								
Tapti	India	19.5-31.5	7.0-8.6	--	5	7-150	—	79-2,400
Godavari(Polavaron)	"	25.0-32.0	6.5-8.7	--	5	<1-34	--	3-280
Chaliyar	"	25.5-33.9	6.1-8.8	--	4	21-1,300	--	110-5,400
Cauveri	"	23.0-30.0	7.4-8.9	--	1	<1-1,800	--	<1-1,800
Waikato	New Zealand	10.4-20.2	7.7-8.3	--	2	<1-11	<1-17	--
2. LAKES/RESERVOIRS								
Temperate waters								
Okusaganii Reservoir	Japan	4.0-21.0	7.1-7.4	--	1	<1-790	<1-490	--
Karj Reservoir	Iran	3.0-12.0	7.6-8.5	120-285	--	--	315-1,100	--
Dariush Kabir Res.	"	7.0-26.0	7.2-8.3	--	1	<1-33	--	--
Totak	Norway	1.3	6.4	--	--	1	--	--
Tropical waters								
Plover Cove Reservoir	Hong Kong	15.0-31.8	7.1-9.2	--	--	<1-110	--	--
3. GROUNDWATER								
Temperate Waters								
Urawa Well Field	Japan	15.1-16.8	7.5-7.8	--	--	<1	--	--
Tropical waters								
Well #1(Tehran)	Iran	15.0-21.0	7.1-7.7	680-714	--	--	<1-100	--
Well #3(Monzelabad)	"	10.0-23.0	7.2-7.9	--	--	--	<1	--
Well #3(Shiraz)	"	15.0-18.0	6.9-7.9	<1	1	<1-4	--	--
Medjerdah Sloughia	Tunisia	21.0-23.0	7.0-7.5	--	3	<1-5	--	--

*Data from Global Monitoring Program, World Health Organization.
All data derived from 1-3 year monitoring results.

Table 15 Water quality monitoring data - extracts from impact stations*

Water source	Country	Water temp°C	pH range	Suspended solids (mgl^{-1})	BOD maximum (mgl^{-1})	Fecal coli 100 ml^{-1}	Fecal strep 100 ml^{-1}	Total coliforms 100 ml^{-1}
1. RIVERS								
Temperate waters (minimum temp. <10°C)								
Exe	U.K.	4.9-21.0	7.0-8.9	1-62	5	70-22,000	6-3,470	--
Rhine	Netherlands	1.2-24.6	6.9-8.3	3-177	15(TOC)	<1-540,000	--	--
Maas	"	3.9-25.5	6.7-8.3	1-310	36	80-80,000	--	--
Safami	Japan	4.5-24.8	7.0-7.4	3-119	4	130-4,900	79-2,400	--
Shimano	"	0.5-24.5	6.7-7.5	9-989	4	10-5,000	80-17,000	--
Yodo	"	4.1-28.4	7.1-7.9	13-65	4	9,300-230,000	--	--
Sefid	Iran	0.0-29.5	7.7-8.3	36-31,700	--	170-16,000	--	--
Tropical waters (temp above 10°C)								
Sabaramati	India	23.0-37.0	7.0-8.8	--	284	20,000-9,900,000	--	170,000-9,900,000
Narmada	"	19.0-32.0	7.0-8.8	--	11	<2-9-900,000	--	8-9,900,000
Subernakekla	"	18.0-40.0	6.8-8.4	--	8	990-46,000	--	900-240,000
Conchos	Mexico	15.0-36.0	6.0-8.3	--	10	200-100,000	7-100,000	--
Balas	"	28.0-30.0	6.7-8.4	10-11,900	3	9-240,000	230-110,000	--
Blanco	"	19.0-27.0	6.0-8.5	4-995	40	4-110,000	--	--
San Pedro	Ecuador	12.0-20.0	6.6-8.3	28-1,250	--	2-100,000	--	--
Ravi	Pakestan	11.0-26.0	7.1-7.7	220-360	3	363-19,000	--	--
Brahmaputra	Bangladesh	20.0-30.0	6.6-7.9	21-69	--	300-7,000	--	--
Chao Phrya	Thailand	24.0-32.0	5.5-8.0	25-280	3	50-35,000	--	--
Prasak	"	23.0-32.5	6.5-9.8	4-72	3	49-11,000	--	--
2. LAKES/RESERVOIRS								
Temperate waters								
Mt. Bold Reservoir	Australia	8.0-23.5	7.3-9.0	1-30	5	<1-190	--	--
Sagami Reservoir	Japan	5.4-27.5	7.0-10.1	--	32	2-3,300	<1-1,100	--
Biwa Lake	"	3.5-29.0	7.4-9.2	3-15	4	23-4,300	--	--
Tropical waters								
Lago de Chapala	Mexico	16.0-23.7	8.4-9.4	4-647	4	3-2,400	3	--
Beni Mtir Lake	Tunisia	12.0-18.0	7.0-7.5	--	-	8-2,400	--	--
Kaptai Lake	Bangladesh	21.0-31.0	7.2-8.0	27-70	4	10-90	--	--
3. GROUNDWATER								
Tropical waters								
Well (Baroda)	India	23.0-32.0	7.0-8.5	--	3	<2-1,100,000	--	<2-1,100,000
Well (Burhampur)	"	20.0-30.5	7.0-8.5	--	4	7-460	--	93-2,400
Well (Tarvai)	"	26.0-32.0	6.6-8.6	--	4	2-540	--	21-920
Well (Eluru)	"	24.8-30.5	5.7-7.3	--	6	4-920	--	43-3,200
Well (Kalpalli)	"	24.0-34.3	6.2-7.7	--	4	7-230	--	40-2,400
Well (Peddavoora)	"	26.1-33.0	6.8-8.5	--	4	<1-640	--	11-1,950

*Data from global Monitoring Program, World Health Organization.
All data derived from 1-3 year monitoring results.

Table 16 Percentage of stations reporting different levels of oxygen balance indicators in GEMS rivers

	Number of stations	5%	10%	50%	90%	95%
BOD mg l^{-1}	190	1.3	1.6	3	6.5	9
COD mg l^{-1}	127	4	6	18	44	60
O_2 saturation per cent	227	55	70	90	105	110

Although sewage effluents are often the main source of organic matter of man-made origin, other industrial sources such as pulp and paper effluents can be significant, especially where sewage effluents are already treated to a high standard. Reduction of these industrial effluents as in Sweden (Figure 13) therefore leads to considerable improvement in water quality. In most areas of the developing countries, however, public water supply by house connection and water-flush toilets with subsequent municipal sewerage systems have not yet been introduced. Therefore, much less organic pollution is discharged to surface waters (Table 17). Individual excreta disposal facilities add organic matter to the sub-soil, a practice which has created under certain circumstances severe ground water pollution problems, particularly in shallow aquifers.

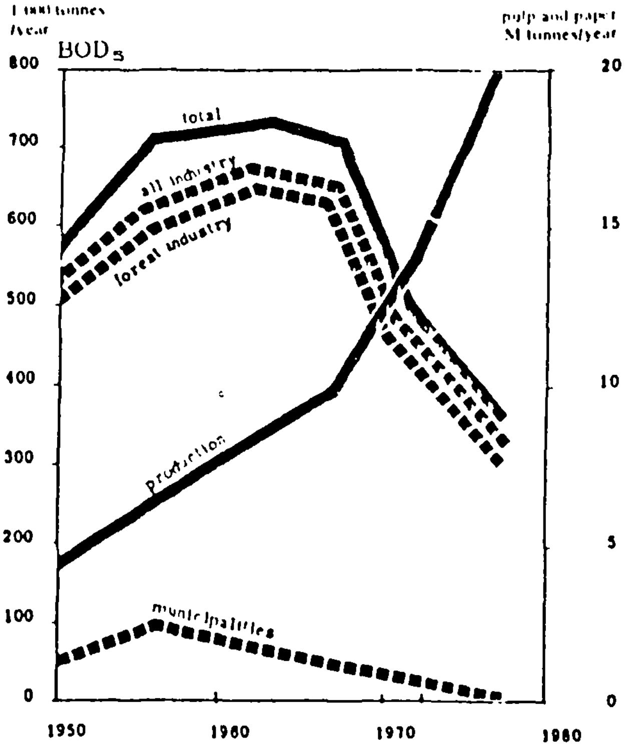


Figure 13 The reduction in water pollution from Sweden's pulp and paper industries

Table 17 Pollution and waste loads from domestic effluents

	People connected to sewer	People not connected to sewer
Waste volume (m^3/person/year)	73	7.3
BOD5 (kg/person/year)	19.7	6.9
COD (kg/person/year)	44	16
SS (kg/person/year)	20	16
Total dissolved solids (kg/person/year)	36.5	–
Nitrogen (kg/person/year)	3.3	–
Phosphorus (kg/person/year)	0.4	–

Source: WHO (1982)

In developing countries, treatment of organic wastes is achieved not only by mechanical/biological treatment plants, but also by long-term processes such as lagoons, stabilization ponds and oxidation ditches. Only the incorporation of the necessary waste treatment measures in urban and industrial development planning will prevent further deterioration in the quality of receiving waters. In Malaysia, for example, it is predicted that reductions in organic waste loads in waste waters from palm oil mills will lead to significant improvements in river water quality (Singam 1982). Figure 14 illustrates the possible effect of wastewater treatment on BOD levels in Malaysian rivers.

4.1.3 Nutrients

Certain inorganic chemicals present in water are essential to metabolism and growth of aquatic organisms. These nutrients are present naturally although considerable quantities are now also added by human activity. The two most important man-made sources are municipal waste water and run-off from agricultural areas fertilized by manure and chemicals. Overloading of water bodies with nutrients leads to eutrophication and algal blooms with detrimental consequences for oxygen balance, organic loads, fisheries and suitability for drinking water.

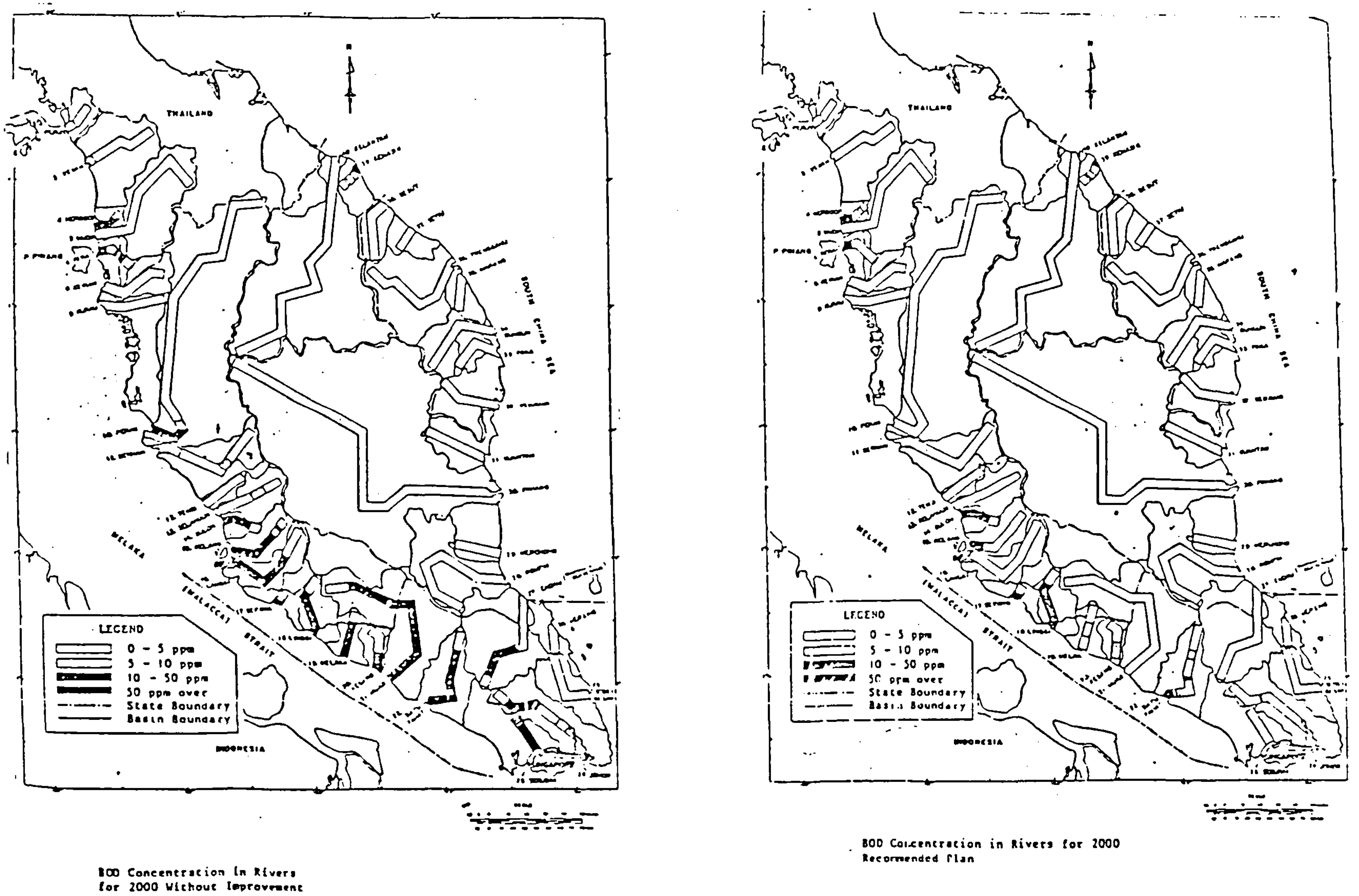
In water monitored by the GEMS/WATER network, the two most important nutrients, nitrogen and phosphorus, are well above natural levels. The median nitrate concentration within the network is seven times higher than the average for unpolluted rivers (0.1 mg l^{-1} nitrate as nitrogen). For the highest 10 per cent of the rivers, concentrations range from 9 to 25 mg l^{-1} NO_3-N; these levels exceed the WHO guideline value for nitrates in drinking water (10 mg l^{-1} NO_3-N). This is of particular importance if the waters are used in the raw state for public supply. The median phosphate level in GEMS/WATER rivers is 2.5 times the average for unpolluted rivers. The worst 10 per cent of rivers carry from 0.2 to 2 mg l^{-1} phosphorus, or between 20 and 200 times higher than the average for unpolluted rivers. The European rivers have the highest average nutrient levels; in some cases nitrate levels are 45 times higher than natural background concentrations as shown in Table 18.

Table 18 Nitrogen levels in GEMS rivers

	Ammonia ($\mu g\ l^{-1}$)*	Nitrates ($\mu g\ l^{-1}$)*
All GEMS rivers outside Europe	70	250
European GEMS rivers	210	4500
Natural average for unpolluted rivers	15	100

* On the basis of nitrogen content

Eutrophication, or the enrichment of waters with plant nutrients, has become an increasing problem in lakes and reservoirs for many years. It is now also found in many river stretches in central Europe (Table 19) and other continents (Table 20). Apart from ecological and aesthetic damage, eutrophication causes increasing difficulties and costs for waterworks which have to produce safe, palatable drinking water. Strategies have been developed, particularly in the OECD countries, to reduce eutrophication. The first step involved the tertiary treatment of wastewater



BOD Concentration In Rivers for 2000 Without Improvement

a) Present state of river water quality in Malaysia

BOD Concentration in Rivers for 2000 Recommended Plan

b) Predicted state of river water quality in Malaysia for the year 2000.

Figure 14 The effect of pollution control measures on river water quality in Malaysia

Source: Singham (1982)

effluents to eliminate phosphates. This strategy has been shown to be effective even in large lakes, as demonstrated by phosphorus levels in Lake Geneva (Figure 15). Through the effective treatment of waste discharges into the lake and its tributaries, the increasing trend in phosphate levels was reversed in the mid-1970s.

A different control strategy to counter eutrophication has been adopted in several North American and European countries, including the riparian states and provinces of the Great Lakes, The Netherlands, Switzerland and Italy, where polyphosphates in detergents have been partially or totally replaced by other chemicals. This strategy enhances the results achieved by treatment but leaves the major problem of non-point sources unresolved, a challenge which the European countries are facing in the 1990s and which will require difficult agricultural policy changes.

Current concerns about nitrates are more in relation to drinking water quality rather than eutrophication, although their role in contributing to eutrophication is well documented. As demonstrated in the case of the Rhine river (Figure 16), ammonia levels were reduced in the river basin following the implementation of extensive waste water treatment measures. Today

Table 19 Eutrophication problems in European countries

	Natural lakes	Reservoirs, rivers and irrigation systems	Estuaries, lagoons	Marine coastal waters
Austria	++			
Belgium		+		
Czechoslovakia		+		
Denmark	++			++
Finland	++		+	+
France	+	++	+	++
Germany (DR)	+	++	+	+
Germany (FR)	++	++	+	+
Greece		+	+	+
Hungary	+	+		
Ireland	+	+		
Italy	++	++	+	++
Norway	++		++	
Poland	++	+		
Portugal		+	+	
Romania				+
Spain		++	+	
Sweden	++		+	++
Switzerland	++			
The Netherlands		++	++	+
United Kingdom	++	+		
USSR	+	++	+	+
Yugoslavia				+

+ = identified problems.
++ = serious problems.

Sources: Vollenweider (1979); Vighi and Chiaudani (1986)

Table 20 Eutrophication problems in countries outside Europe

Geographic region and countries	Natural lakes	Reservoirs, rivers and irrigation systems	Estuaries, lagoons and closed seas	Marine coastal waters
North America				
Canada	++	+	+	
U.S.A.	++	++	++	+
Central America				
Mexico	+	++		
Guatemala/ Nicaragua	+			
Caribbeans	+	+		+
South America				
Venezuela/Surinam	+	+	++	
Columbia/Ecuador/ Peru	+	++	+	+
Brazil	+	++	++	+
Argentina/Chile	+	++	+	
Africa				
North	+	++	+	
Central	+	++	+	
South		++		
Asia				
India/Pakistan	+	++	+	
Indochina	+			
China	++	+	+	
Japan	++	+	++	+
Indonesia/ Philippines		++	+	
Australia & New Zealand	++	+	+	

\+ = identified problems.
++ = serious problems.

Source: Vollenweider (1979)

levels are below the 1960 concentrations. However, nitrate levels have been less affected due to possible nitrification and to uncontrolled contributions from non-point sources, mainly fertilizer leachates from agricultural areas in the drainage basin - see section 4.3.4.

Although surface waters in developing countries have, in general, not reached alarming nutrient levels, there are a number of locations where eutrophication interferes with water use for human consumption. The Laguna de Bay Lake in the Philippines, for example, has been selected for the future public water supply for Metro Manila, although its present water quality would not

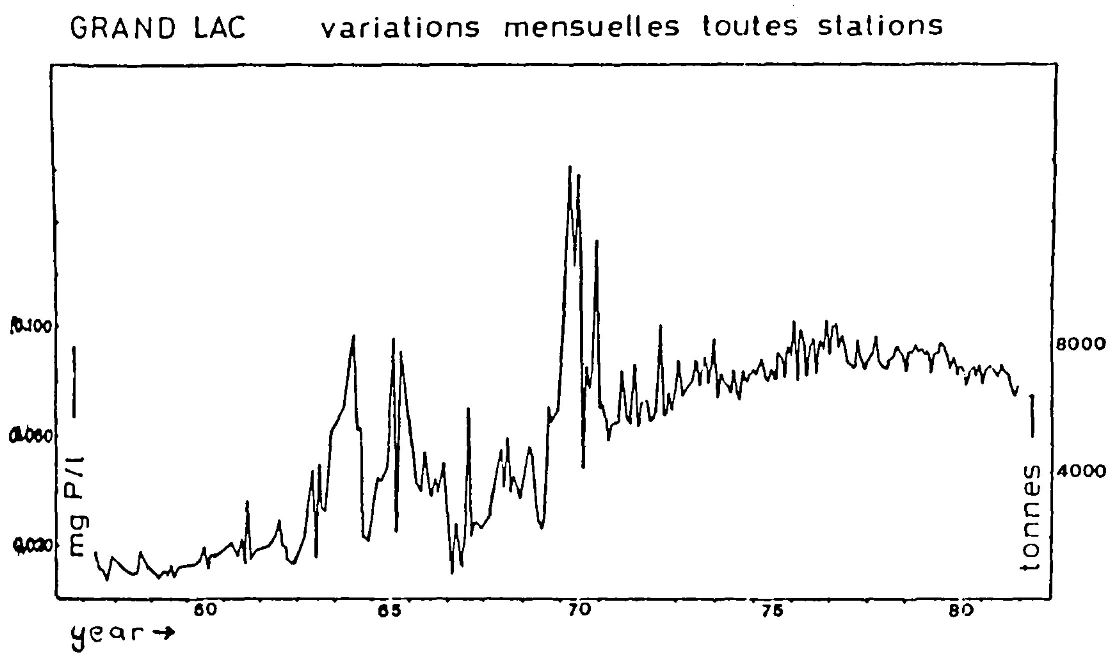


Figure 15 Eutrophication in Lake Geneva as given by total phosphorus levels

Source: CIPEL (1983)

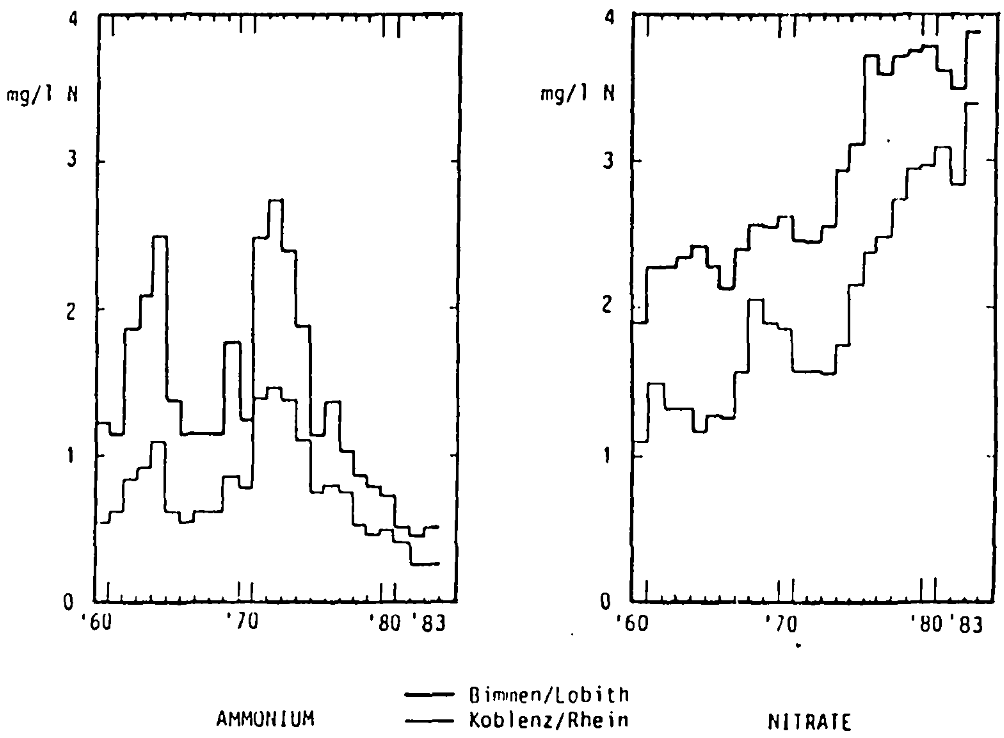


Figure 16 Ammonium and nitrate levels in the Rhine, 1960-1983

Source: Com. Int. du Rhin (1984)

allow this. The main problems are heavy nitrogen loads from pig farming around the lake which have led to severe eutrophication. In Morocco and China several reservoirs or lakes required for urban supply have been seriously affected by eutrophication and studies are currently being made which aim to maintain their water quality for human consumption. These examples are given to indicate that developing countries are not safe from the effects of nutrient discharges which have traditionally been considered a phenomenon of the more industrialized countries.

4.2 Industrial Effluents and Emissions

Industrial processing of raw material and utilization of chemicals in production of goods usually involves release of potentially toxic materials into the air or water. Among these compounds heavy metals and synthetic organic chemicals are of primary concern because of their adverse effects on organisms even at relatively small concentrations. Catastrophic events of water related poisonings, for example by mercury, cadmium and organic pesticides, prompted during the 1960s and 1970s increased efforts to reduce emissions from industrial sources, especially in the more developed countries. However, many different problems with industrial emissions into aquatic systems still exist. For heavy metals major concerns have been identified in relation to mine effluents and dredged sludges (Salomons and Forstner 1988). In the case of organic chemicals, factories where pesticides and PCBs are manufactured should be considered as a matter of priority.

The onset of the Second World War led to a rapid expansion and diversification in industrial production in many areas around the world. As a consequence by-products and organic and inorganic wastes have been accumulating at an increasing rate with only limited provision for disposal. Often such wastes are simply put into drums and placed in dumps. Examples of substances dealt with in this way include trace metals, phthalates, haloethers, chlorinated hydrocarbons, pesticides, PCBs, dioxins, benzofurans, polynuclear aromatic hydrocarbons and radioactive compounds. As a result of long-term storage some problems have arisen with deterioration of the drums allowing leakage of the contents. In developed countries such waste dumps, accumulated over 30-40 years, are producing potential contamination risks for surface waters and groundwaters. However, hazardous waste disposal and dump sites are becoming subject to control and regulation although existing sites still present problems of decontamination and disposal. Consequently, as regulations are strengthened in the more developed countries unscrupulous operators are attempting to dispose of such wastes in countries with less stringent regulations.

4.2.1 Trace Elements

With respect to the potential impact of heavy metals on the environment it has been estimated that about 0.5, 20, 240, 250, and 310 million tonnes of cadmium, nickel, lead, zinc and copper respectively have so far been mined and ultimately released into the atmosphere and biosphere (Nriagu 1979). In many instances, emissions from anthropogenic sources exceed the contribution from natural sources. However, elevation of heavy metal levels in water bodies by man on a global scale has only been indicated for lead in profiles taken from marine and lacustrine environments.

Generally it can be stated that significant anomalies of trace metals in aquatic systems are found on a local or regional, rather than on a global scale, as levels are usually affected by regional geochemical factors or by dominant localized (mostly industrial) inputs of metal contaminants. An inventory in Lake Erie by Nriagu et al. (1979) revealed that on a regional basis, contributions from sewage effluents accounted for 45 per cent, 30 per cent and 20 per cent of the copper, zinc and lead discharges respectively. In the Ruhr River catchment area of West Germany approximately 55 per cent of the heavy metals (Pb, Cu, Zn, Ni, Cr, Cd) are discharged from municipal and industrial waste water treatment plants. These municipal treatment plants receive nearly 70 per cent of their heavy metals from industrial waste water. The origin of the elements and their relative fractions varies considerably; for example, 90 per cent of the chromium in the Ruhr River is discharged by industries, but for copper and zinc this fraction is approximately 50 per cent (Imhoff et al. 1980).

Data for trace elements (heavy metals and arsenic) have been reported from 110 GEMS/WATER stations. Total concentrations (i.e., from unfiltered samples) have been measured for between 38 (As) to 66 (Cu) stations. Dissolved concentrations have been determined for between 19 (Cr) and 55 (Cu) stations. Table 21 summarizes statistically the results obtained. The most complete data sets (number of elements; both total and dissolved concentrations) arise from stations in the United States (20 rivers). Dissolved concentrations, representing the more reliable data, were determined from several stations in Norway, Sweden, The Netherlands, Brazil, Chile and Thailand.

Table 21 Levels of heavy metals and arsenic (total and dissolved) in GEMS rivers and lakes, 1982-1984 ($\mu g\ l^{-1}$)

Element	No of Data from 168 Statns		Median		Percentil 10-90		Maximum Val.	
	Total	(Diss.)	Total	(Diss.)	Total	(Diss.)	Total	(Diss.)
As	38	(33)	2.5	(<1.0)	<1-10	(<1- 3)	30[a]	(40)[b]
Cd	56	(45)	1.0	(<1.0)	<1- 5	(<1- 2)	312[c]	(100)[b]
Cr	58	(19)	10	(<1.0)	3-17	(<1- 6)	1675[d]	(8)[e]
Cu	66	(55)	10	(5)	4-18	(<1-20)	80[f]	(2510)[g]
Hg	59	(34)	0.1	(<0.1)	<0.02-0.5	(<0.1-0.23)	0.5[h]	(0.44)[i]
Mn	61	(39)	50	(10)	10-280	(<10-60)	1350[k]	(320)[b]
Pb	64	(54)	6	(2)	2-16	(<1-20)	50[l]	(220)[b]
Zn	51	(33)	20	(16)	5-68	(5-115)	400[d]	(580)[b]

Maximum Values:

	Total	**Dissolved**
As	[a] Klang River, Malaysia	[b] Rio Rimao Lima, Peru
Cd	[c] Missouri River, U.S.A.	" " " "
Cr	[d] Espierre R. (Leers/Belgium)	[e] Delaware River, U.S.A.
Cu	[f] Lake Huron, Canada	[g] Rio Mapocho/Los Almendros
Hg	[h] 9 different rivers in Japan	[i] Pampanga River, Philippines
Mn	[k] Ghent, Zelzate/Belgium	[b] Rio Rimao Lima, Peru
Pb	[l] Ohio River, U.S.A.	" " " "
Zn	[d] Espierre R. (Leers/Belgium)	" " " "

Current GEMS/WATER data can be evaluated for indications of (i) natural background values, (ii) excessive enrichment due to pollution or natural effects, such as mineralization, and (iii) temporal variations of the metal concentrations. With respect to the latter, it seems that the time period of extensive data evaluation is not sufficient for an interpretation of these complex interactions of contributing factors such as water discharge, particulate matter concentrations and input of pollutants. The Rhine River (Figure 17), has been intensively studied for 15 years and therefore gives an indication of the general trends, at least in more polluted areas.

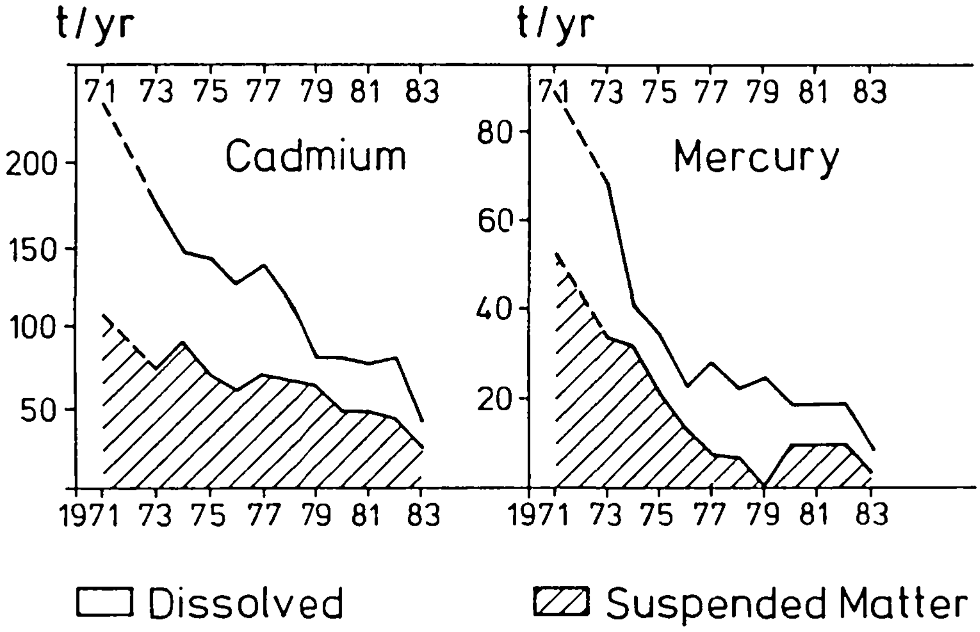


Figure 17 Mercury and cadmium loads (dissolved and particulate) in the Rhine River at the Dutch-German border, 1971-1983

Source: Malle (1985)

For an evaluation of natural background concentrations the dissolved metal concentrations in the lower region of the spectrum of values should be considered. It should, however, be noted that the natural background values of many of the elements listed in Table 21 are well below the analytical limits considered in the present GEMS/WATER programme. With respect to the maximum concentrations listed in Table 21 the effect of pollution is most significant in the examples where total concentrations have been determined, such as the Missouri River (Cd), Ohio River (Pb), Espierre River, Belgium (Cr, Zn), and various rivers in Japan for mercury. For dissolved concentrations there is still some debate on the sources of excessive enrichments. There is no doubt that heavy metal contamination occurs in several rivers in the Philippines, Japan, China, Turkey, Panama, Mexico, U.S.A. (Rio Grande) and Chile. In Chile the high copper value reported for the Rio Mapocho needs to be confirmed, since this river is classified as a baseline station. Elevated copper concentrations may be due to unsuspected pollution or to a high natural background value (WHO 1983b).

In developing countries severe pollution with heavy metals can occur where large scale mining and smelting operations are undertaken. The most severe problems are usually found downstream of mining areas and are often due to the lack of appropriate control installations.

However, even in developed countries metal concentrations in rivers can be considerably in excess of background levels (Table 22). Since arsenic is naturally present in lead, copper and gold ores, it becomes available during smelting as gaseous or solid waste by-product. Thus man-made sources currently outnumber natural sources by 3:1 (Hindmarsh and McCardy 1986). However, as far as drinking water is concerned, groundwater enriched through the weathering of arsenic bearing minerals is generally the most important source. There are a few geologically determined areas in Asia and Latin America, where dermatological effects (*Blackfoot* disease) were the first manifestations in villages depending on arsenic-rich well-water supplies. At chronic poisoning levels, various effects are observed such as inflammations, skin lesions and neurological effects. Using a linear non-threshold model a WHO Task Group estimated that a lifetime exposure to arsenic in drinking water at a concentration of 0.2 mg l^{-1} gave a 5 per cent risk of contracting skin cancer (WHO 1981). Since arsenic is of no essential value to the human metabolism, it is a typical example of substance B in Figure 9.

Table 22 Dissolved and particulate concentrations of cadmium, lead and copper in the River Elbe compared to background levels

	Dissolved Metals (ng l^{-1})			Particulate Metals (mg kg^{-1})		
	Cadmium	Lead	Copper	Cadmium	Lead	Copper
Upper Elbe	35	65	2200	20	300	500
Lower Elbe	35	25	1000	1	100	150
Background	10	20	500	0.3	20	45

Source: Turekian and Wedepohl (1961); Sigg et al. (1982); Mart et al. (1985)

4.2.2 Organic Pollutants

Most organic pollutants originate from major industrial activities such as petrol refining, coal mining, organic synthesis and the manufacture of synthetic products, the iron and steel industry, the textile industry and the wood pulp industry. The effluent from factories where pesticides are manufactured may also contain considerable quantities of these products. On the basis of an enquiry covering several such factories, the U.S. EPA estimated that the flows of pesticides in wastewaters ranged from 0.3 to 2.8 kg t^{-1} of manufactured product. The average concentrations of pesticides in the effluents ranged between 10 and 80 mg l^{-1}. In contrast to the spreading of these products in agriculture, contamination with pesticides in industrial effluent is characterized by the high pesticide content of the waste and its narrow localization. Several examples of pollution of surface waters can be cited, such as that of the James River in Chesapeake Bay in the U.S.A. with kepone, a chlorinated insecticide (Huggett and Bender 1980) or of the Bay of California with effluent from a DDT factory (Young et al. 1977). Pesticides are also found in the effluent from factories using these products, such as those where wood is worked (e.g., dieldrin in quantities of 12 to 65 mg l^{-1}), in textile plants, particularly from wool and carpet washing units (malathion, lindane, dieldrin, etc.) and agricultural and food industries (Sauvegrain 1981).

A preliminary assessment of the quality of continental waters (rivers, lakes and groundwater) can be obtained by examining the data collected by the GEMS/WATER network. The organic pollutants measured by this programme and categorized to be of world importance consist solely of organochlorine pesticides and the polychlorinated biphenyls. Monitoring was carried out from 1979 to 1984 in about 25 per cent of the stations in operation (Table 23). A noteworthy feature is the absence of any such measurements in the African countries (except for one surveillance station in Tanzania which stopped monitoring in 1982), in the Middle East and in South America (except for one station in Columbia since 1982). In general three chlorinated insecticides are measured, namely DDT and its metabolites, aldrin and dieldrin. Certain countries also monitor other insecticides, including isomers of hexachlorocyclohexane (HCH), endrin and mirex (Table 24). Although the polychlorinated biphenyls (PCBs) represent a global indication of contamination of the aquatic environment, they are only infrequently measured.

Table 23 The number of monitoring stations at which organic pollutants are measured in the GEMS/WATER programme, 1979-1984

	Rivers	Lakes and reservoirs	Groundwater	Total
World Network GEMS/WATER				
designated sites	301	62	85	448
operating sites	240	43	61	344
Monitoring for ogranic pollutants				
Americas				
USA	12	0	0	12
Canada	5	0	0	5
Columbia	1	0	0	1
Europe				
UK	5	1	1	7
Netherlands	5	1	0	6
Finland	3	2	0	5
Belgium	1	0	0	1
Portugal	1	1	0	2
Spain	5	0	1	6
Asia				
Thailand	2	1	0	3
China	3	1	0	4
Japan	6	3	2	11
Malaysia	5	0	0	5
Philippines	2	1	0	3
Indonesia	6	1	4	11
Oceania				
New Zealand	3	0	1	4
Australia	0	1	0	1
Africa				
Tanzania	1	0	0	1
Total	66	13.	9	88
% of operating stations monitoring organic pollutants	27%	30%	14%	25%

Table 24 Organic pollutants measured in the GEMS/WATER programme, 1979-1984

	PCB	DDT [1]	Aldrin	Dieldrin	Endrin	Mirex	αHCH	HCH
Americas								
USA			x	x	x	x		
Canada		x	x	x	x	x	x	
Columbia		x	x	x				
Europe								
UK	x	x	x	x				x
The Netherlands		x	x	x				
Finland	x	x	x	x				
Belgium		x						
Portugal		x	x	x	x			
Spain		x						
Asia								
Thailand		x	x	x				
China		x					x	x
Japan	x	x	x	x			x	x
Malaysia		x	x	x				x
Philippines		x	x	x				x
Indonesia	x							
Oceania								
New Zealand	x	x	x	x			x	
Australia								x
Africa								
Tanzania				x				

[1] and metabolites

There are many problems associated with monitoring for toxic organic chemicals. Sample contamination can lead to inaccurate measurements and the complex composition of the chemicals can also lead to incomplete identification. Since many organic chemicals have low ambient concentrations the methodology is often complex and expensive resulting in a lack of monitoring in some regions including many developing countries. Much effort in the past has been put into attempting to measure the chemicals in the water itself rather than the sediments or other suitable medium. Thus the potential use of biomonitoring techniques and the use of bioassays for assessment of total toxicity have not been fully exploited at this time.

The concentration of organic chemicals measured are generally below 10 ng l^{-1} and when the detection limits are sufficiently low the average levels range from 3 to 7 ng l^{-1}. This is the case in the Susquehanna and Potomac rivers in the U.S.A. (aldrin, dieldrin), the River Chao Phrya in Thailand (DDT, aldrin, dieldrin, HCH), the Kymijake River in Finland (PCBs) and the monitoring stations in Spain (DDT). Markedly higher levels, ranging from 100 to 1,000 ng l^{-1}, were reported from the River Trent in Great Britain for PCBs, from the Chinese rivers for HCH isomers and from several monitoring stations (Lake Biwa, and the Yodo and Ohta rivers) in Japan for PCBs. Finally, levels above 1,000 ng l^{-1} , which indicate either extremely worrying levels of pollution or an inability to use the analytical protocols properly, were found in the rivers Rufigi in Tanzania (dieldrin; 30 μg l^{-1}), Canca Juanchito in Colombia (DDT; 1.2 μg l^{-1}; dieldrin; 3.0 μg l^{-1}), Gombak in Malaysia (dieldrin; 30.6 μg l^{-1}) and all the monitoring stations in Indonesia (PCBs from 0.4 to 6.9 μg l^{-1}). In general pollution of continental waters by pesticides has not been observed at significant levels in the rivers of the U.S.A. and Canada or in most of the monitoring stations in several countries in Europe (Netherlands, Finland and Great Britain) and

Asia (Thailand, Japan and Malaysia). Table 25 summarizes the range of levels reported to the GEMS/WATER programme for chlorinated hydrocarbons. As a result of the contamination of water resources, these organics can also be found in trace concentrations in drinking water.

Table 25 Levels of chlorinated hydrocarbons (insecticides and PCBs) measured in the GEMS/WATER programme, 1979-1984

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

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

4.3 Land Use Activities

Land use by man, from deforestation to intensive agriculture, greatly affects the quality of all water bodies, rivers, lakes, reservoirs and groundwaters. In addition, open-cast mining operations and leaching of mine tailings, sometimes from operations discontinued a long time ago, may cause major deterioration of water quality through heavy metal leaching and sulphuric acid production during the weathering of tailings. However, the most visible and, in many areas, most serious effect is that of increased suspended matter in rivers, though in rivers not affected by human activities suspended matter is one of the most variable characteristics of water quality, with average levels over one year ranging from 1 to more than 10,000 mg l^{-1}. A summary of the range of environmental effects caused by agriculture on water quality is presented in Table 26.

4.3.1 Deforestation, Damming and Suspended Solids

Deforestation has always been a human practice but has now reached such proportions that it is indirectly causing severe degradation of water resources. In many developing countries deforestation is widespread, causing loss of soil nutrients through water leaching and increase of surface water turbidity due to the subsequent soil erosion. Initial deforestation may increase the sediment load in rivers more than 100 times for a short period of time. As a consequence, many tropical rivers are now highly turbid during the rainy seasons, although it is difficult to present specific examples of this effect due to a lack of appropriate monitoring. Table 27 summarizes certain sediment data for some of the major world rivers.

Table 26 Selected environmental effects of agriculture on water quality

Agricultural Practices	Soil	Ground water	Surface water
Land development: land consolidation programmes	Inadequate management leading to soil degradation	Other water management influencing ground water table	
Irrigation, drainage	Excess salts water logging	Loss of quality (more salts), drinking water supply affected	Soil degradation, siltation, water pollution with soil particles
Tillage	Wind erosion, water erosion		
Mechanism: large or heavy equipment	Soil compaction soil erosion		
Fertilizer use			
- Nitrogen		Nitrate leaching affecting water	
- Phosphate	Accumulation of heavy metals (Cd)		Run-off leaching or direct discharge leading to eutrophication
- Manure, slurry	Excess: accumulation of phosphates copper (pig slurry)	Nitrate, phosphate (by use of excess slurry)	
- Sewage sludge compost	Accumulation of heavy metals, contaminants		
Applying pesticides	Accumulation of pesticides and degradation products	Leaching of mobile residues and degradation products	
Input of feed additives, medicines	Possible effects		
Modern building (e.g. silos) and intensive livestock farming	See slurry	See slurry	See slurry

Source: OECD (1985a)

Table 27 Sediment discharge and average levels of suspended matter in major world rivers

River	Average sediment discharge (10^6 t yr^{-1})	SM mg l^{-1}	Adequacy of data base
1. Ganges/Brahmaputra	1,670	1,700	Inadequate
2. Amazon	1,110-1,300	200	Inadequate
3. Yellow (Huangho)	1,080	23,000	Good
4. Yangtze	478	550	Good
5. Irrawaddy	285	650	Inadequate (?)
6. Magdalena	220	1,000	Inadequate
7. Mississippi	210	360	Good
8. Hungho (Red)	160	-	Adequate
9. Mekong	160	280	Sufficent
10. Orinoco	150	140	Sufficient
11. Indus	100	1,000	Sufficient
12. MacKenzie	100	300	Poor to fair
13. Godavari	96	-	Inadequate
14. La Plata	92	200	Inadequate to sufficient
15. Haiho	81	-	Good
16. Purari	80	-	Inadequate
17. Zhu Jiang (Pearl)	69	300	Sufficient to good
18. Copper	70	-	Sufficient
19. Danube	67	350	Good
20. Choshui	66	-	Sufficient
21. Yukon	60	320	Sufficient

Source: Milleman and Meade (1983); Meade (1987 pers. comm.)

Total suspended solids are measured at 52 per cent (137) of the GEMS/WATER river stations and at more than 50 per cent of the lake stations. In Asia (excluding the Soviet Union), there are 70 river stations, with suspended solids monitored at 78 per cent of the major and 68 per cent of the minor ones. As for many other variables, the African continent is least surveyed for suspended matter, particularly in East Africa from Ethiopia to Lesotho, where it is nevertheless known to be a major problem. However, high levels are reported from India, China, Indonesia, Iran and Iraq. In areas of the world such as North America, the U.S.S.R. and China where soil erosion, reservoir silting and flood plain deposition are of particular concern, national surveys for suspended matter are also conducted. Probably the largest water quality monitoring network is the U.S. National Stream Quality Accounting Network (NASQAN) operated by the U.S. Geological Survey which samples more than 300 rivers monthly. The most extended global network is probably the one operated during the 1960s and the 1970s by the International Association for Scientific Hydrology (IASH 1974) in which more than 300 rivers were classified according to drainage area and climate. Some statistics resulting from this programme on the frequency distributions of suspended matter are given in Table 28.

Table 28 Statistical distribution of average suspended matter levels in world rivers (mg l^{-1})

	10%	50%	Mean	90%	99%	n(1)
Global distribution						
GEMS rivers (2)	5	35		250		137
World major rivers (3)	20	150	450 (7)	1000	3000	60
Regional distribution						
U.S. rivers (4) average	7	70		1000	15000	300
yearly maximum (6)	15	160		2500	80000	
Global IASH network (5)						
10 - 1000km^2	40	700		6000		40
1000 - 10000 km^2	70	600		4500		50
10000 - 1000000 km^2	40	180		1000		38
Total:	55	450		4500		128

(1) number of rivers considered
(2) GEMS/Water Data Summary Report
(3) Meybeck (1982)
(4) Briggs and Ficke (1977)
(5) based on Fournier (1969)
(6) statistical distribution of yearly maximum observed (from Briggs and Ficke 1977)
(7) discharge-weighted average for all rivers going to oceans

River damming is now widespread on most continents (e.g., Columbia, Colorado, Rio Grande, Missouri in North America; Panama, Caroni in South America; Volta, Zambezi, Nile, Niger in Africa; Volga, Dnepr in Europe; Indus and Chiang Jiang (Yangtze) in Asia) and can result in multiple effects on water quality. Sediment retention may lead to a clearing of waters below the dam (followed generally by an increase in shore erosion downstream), which is sometimes detrimental for irrigation through the loss of natural particulate nutrients, as shown for the Nile in Figure 18. Eutrophication within the reservoir may increase due to the increased residence time and transparency of the waters as observed in many sub-tropical reservoirs (e.g., Morocco and Brazil). This can even lead to complete anoxia of bottom waters. Flooding of organic-rich soils also causes oxygen consumption from reservoir water even if the nutrient levels of the water are very low. Other effects include drastic changes of downstream water quality during sluicing operations (ammonia release, very high turbidity) and health-related problems along the shore lines of tropical reservoirs (parasites, malaria).

4.3.2 Mining Activities

Pollution from mining activities, either through direct release into the rivers or through leaching of mine tailings into groundwaters still poses considerable problems, even in the more developed countries.

The most important group of aquatic pollutants derived from mining operations are heavy metals which are present in discarded mine tailings and in runoff water from the mining process. Very high levels of heavy metals are found in acidic mine effluents world-wide. A summary of the metal concentrations observed in different areas around the world is shown in Table 29. Environmental degradation in these areas is reported to be severe. For a discussion of GEMS/WATER data relating to heavy metals see Section 4.2.1.

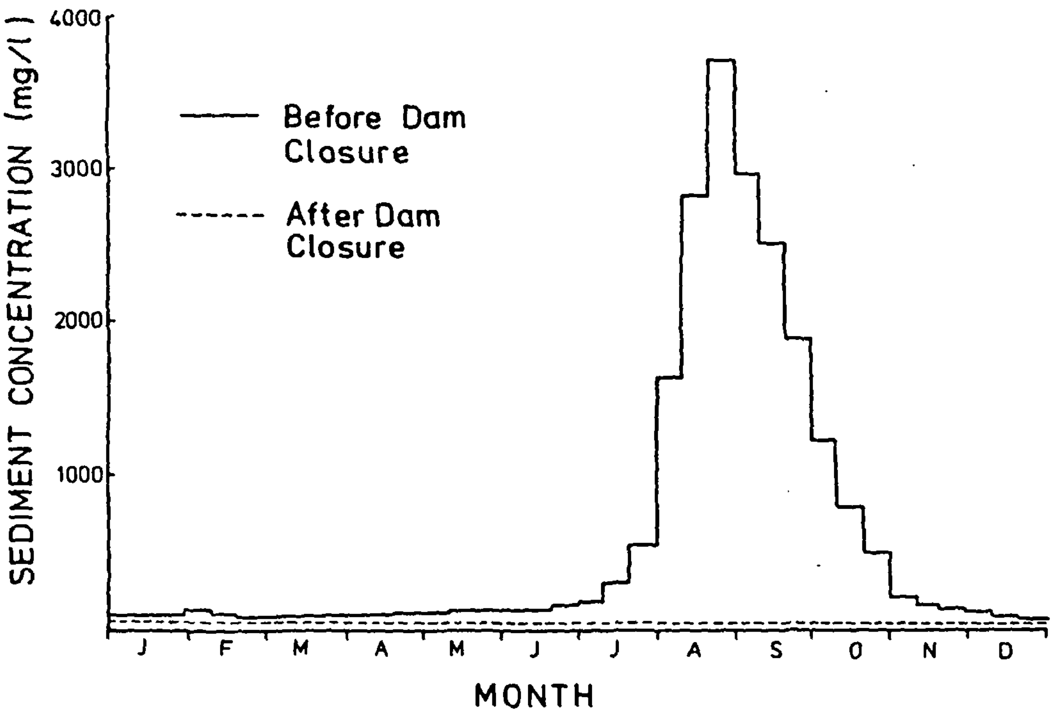


Figure 18 Sediment concentrations in the Nile before and after the closure of the High Dam at Gaafra, 35 km below Aswan

Source: Scamp (1983)

Table 29 Metal concentrations in inland waters affected by acidic mine effluents

Metal	Cornwall (SW England)	Silesia (Poland)	Siberia[f] (USSR)	Colorado[g] (U.S.A.)	Philippines (h)	Tasmania (i)
As	250[a]	-	499	70	-	-
Cd	-	1.325[d]	207	70	-	6.100
Co	-	15[e]	368	-	-	-
Cr	-	17[e]	-	-	120	-
Cu	1.160	62[e]	20.710	3.900	953	1.350
Fe	23.000[b]	3.185[e]	-	213.000	176.100	20.500
Mn	2.400[b]	315[e]	1.624	8.000	-	22.500
Ni	-	14[e]	900	460	80	-
Pb	530[c]	23[e]	2.071	300	443	-
Zn	10.000[b]	43.100[d]	5.770	17.000	1.280	105.000

[a] Tamar River (Aston et al. 1975); [b] Carnon River; [c] Gannel River (Aston et al. 1974); [d] Graniczna Woda, inflow to [e] Mala Panew (Pasternak 1974); [f] maximum values from up to 4.500 samples (Udodov and Parilov 1961); [g] Hill (1973); [h] Baguio Mining District, Agno and Bued Rivers (Lesaca 1977); [i] Storys Creek in South Esk catchment (Tyler and Buckney 1973)

Source: Forstner (1981)

Another important contaminant arising from mining activities is high salinity water or brine. Drainage from the Lorraine salt mines and the Alsace potash mines in Europe has contributed, along with other sources, to high salinity in the Upper Rhine alluvial aquifers and in the Rhine itself (Figure 19). This salinity prevents the use of Rhine water for greenhouse cultivation of horticultural crops in The Netherlands. Although control measures instituted since the 1970s have produced a substantial decrease in salinity in the aquifer near to the source, brine is still being discharged into the Rhine. This makes an important contribution to the overall salinity of the river, which is not decreasing. Increased salinity is, however, also linked to irrigation practice and the geology of the watershed; these are discussed in the following section.

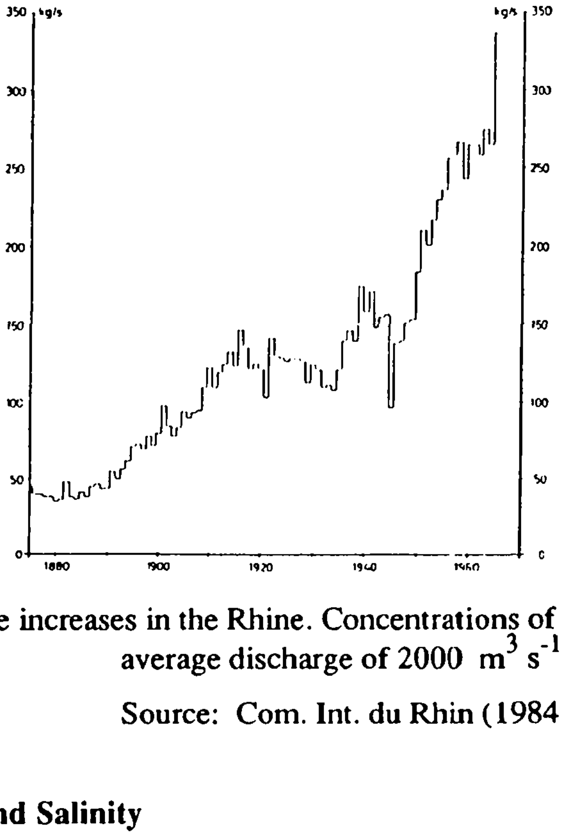


Figure 19 Chloride increases in the Rhine. Concentrations of chloride are estimated for an average discharge of 2000 $m^3 s^{-1}$

Source: Com. Int. du Rhin (1984)

4.3.3 Irrigation and Salinity

The effects of increased salinity arising from irrigated agriculture can be considered as an acute regional problem, largely restricted to the arid and semi-arid areas of the world. Some countries that are particularly affected are listed in Table 30. Country statistics for total irrigated area are relatively easy to obtain but the statistics for the area affected by salinity are much less readily available. It is estimated that of the 270 million hectares presently irrigated world-wide, 60 - 80 million hectares are affected to some extent and a further 20 - 30 million hectares are severely affected. In the future, other areas could be affected by salinity problems. If irrigation is extensively developed in the Zambezi and Limpopo river systems in southern Africa, for example, salinity problems will probably be encountered there.

Rapid population growth means that pressure to increase the area under irrigation will continue. The present global growth rate of irrigated areas of 2 per cent per annum would need to be doubled to keep pace with population growth and avoid massive food deficits. However, salinity and waterlogging from irrigated agriculture is increasing at a rate such that land is going out of production at 30 to 50 per cent of the rate at which new land is being brought under irrigation. Effective management of waterlogging and salinity requires political will, highly developed institutional arrangements and enormous financial resources if irrigated agriculture is to be sustained at the required levels.

Table 30 Areas affected by high salinity and waterlogging as a result of irrigation

Country	Total Irrigated Area		Area Affected by Salinity		Notes
	(million ha)	(year)	(million ha)	(year)	
India	50	1985	12	1977	
USA	21.5	1982	4	1985	
USSR	12.7	1982	na	_	
Pakistan	12.4	1982	3.2	1987	80% of irrigated land is affected in Punjab
Iran	5.2	1982	1.2	1977	
Iraq	4	1982	0.45	1977	More than 50% of the irrigated land in the Lower Rafidain Plain is affected
Egypt	2.9	1982	0.8	1970	Mostly in north part of Nile delta

Conductivity, chloride and alkalinity are the most widely measured variables related to salinity within the GEMS/WATER network (Table 31). However, other related variables including certain toxic elements are being monitored at fewer stations. The data generated from the network are summarized in Table 32 which indicates certain situations where water guideline values are exceeded. The major ions, sodium, chloride and sulphate are high in Iran, North-West India, Australia and Mexico. Fluoride has been shown to be an essential element for some animal species and the incidence of dental caries in humans decreases as the concentration of fluoride increases up to 1 mg l^{-1}. However, adverse health effects are detectable at levels in excess of 1.5 mg l^{-1} and hence this is the recommended guideline value (WHO 1984a,b). Sodium salts are not generally acutely toxic substances because of the efficiency with which the mature kidney excretes sodium. Moreover, most humans can adapt to high concentrations of sulphate and chloride. WHO guideline values are therefore primarily based on taste considerations. Although the human tolerance for total dissolved solids is rather high and flexible, the ions mentioned above pose limits on the potability of water. Consequently, certain ions are included in the GEMS/WATER programme together with conductivity which increases with salt content.

4.3.4 Fertilizer Application and Nitrates

The exponential increase in world fertilizer use is well documented. Much of this consumption occurs in the United States and Europe, but similar exponential increases in fertilizer usage are now seen in the rapidly developing countries and are even beginning to occur in some of the less well-developed countries, especially some of the oil-rich ones. A comparison of nitrogenous fertilizer application rates in selected OECD countries is given in Table 33 which shows that dramatic increases in fertilizer use have occurred during the past two decades. In Europe and North America fertilizer is applied primarily to non-irrigated arable and grazing lands and to a much lesser extent to irrigated agriculture. Application rates are fairly uniform and well-known (100-200 kgN ha^{-1}), and extensive and detailed research has been carried out into the leaching of nitrate from temperate agricultural land under a wide range of geological, soil, climate and

Table 31 Percentage of GEMS stations monitoring salinity related variables

Variable	Rivers	Lakes and Reservoirs	Groundwater
Electrical Conductance	95	75.9	75.9
Chlorine	98	90	75.9
Alkalinity	88	75.9	90
Sulphate	59	50.75	25.5
Flouride	40	25.5	50.75
Sodium	48	25.5	25.5
Arsenic	26	10.25	5.1

Source: WHO (1983a)

Table 32 Water quality at GEMS stations in relation to drinking water guideline values

Variable	WHO Guideline Value (mg/l)		No Exceeding Guideline		Range of Exceedence Measurements
			Stations	Observations	
Chloride	200	a)			
		b)			
Sulphate	400	a)	5	15	416-1870
		b)	1	4	426-506
Sodium	200	a)	8	36	203-2887
		b)	5	34	210-1168
Fluoride	1.5	a)	4	4	1.6-6.6
		b)	–	–	–
Iron	0.3	a)	84	1757	0.31-98
		b)	4	37	0.4-2.8

(a) rivers (b) groundwaters

Source: WHO (1983a)

Table 33 Application of nitrogen fertilizers to agricultural land in selected countries (1), 1961-1981 (kg ha^{-1})

	1961-65	1966	1968	1971	1973	1976	1978	1979	1981
Netherlands	125.2	150.0	152.3	175.6	196.1	207.4	215.0	239.0	236.9
Japan	122.3	142.2	155.8	117.7	145.4	132.9	131.6	141.9	118.2
Denmark	50.9	71.0	82.2	104.5	122.3	118.8	129.6	134.9	129.8
Norway	56.4	63.2	69.3	87.5	94.4	106.0	114.1	118.7	113.8
Germany (FR)	53.7	63.3	67.2	83.3	82.0	99.7	102.8	120.0	108.5
Sweden	32.8	42.8	51.3	62.2	70.9	69.4	68.7	69.1	67.5
Great Britain	29.5	38.8	44.0	49.4	46.8	59.8	66.5	71.2	75.7
France	22.3	29.3	37.5	46.7	56.5	56.6	62.1	67.1	69.6
USA	8.1	11.5	13.1	15.2	17.7	20.7	21.0	24.2	23.5
Canada	2.1	4.3	3.8	5.3	7.8	9.1	12.3	12.2	13.8
Australia	0.1	0.2	0.4	0.3	0.4	0.4	0.5	0.5	0.5

1. These figures are averages for all agricultural land including marginal and upland areas not normally fertilized.

Source: OECD (1986)

cropping conditions. Where fertilizer use is associated with intensive irrigated agriculture, particularly where double or triple cropping of horticultural crops is concerned, as is common in tropical countries, then the application rates can be much higher (300-500 kgN ha^{-1}) and the increased hydraulic loading may produce much greater leaching. This is reflected in the high nitrate concentrations observed in irrigation return flows and occasionally in shallow aquifers below intensively irrigated land such as in Sri Lanka (Figure 20). This effect may, however, be somewhat offset by the dilution of the greater volume of infiltration.

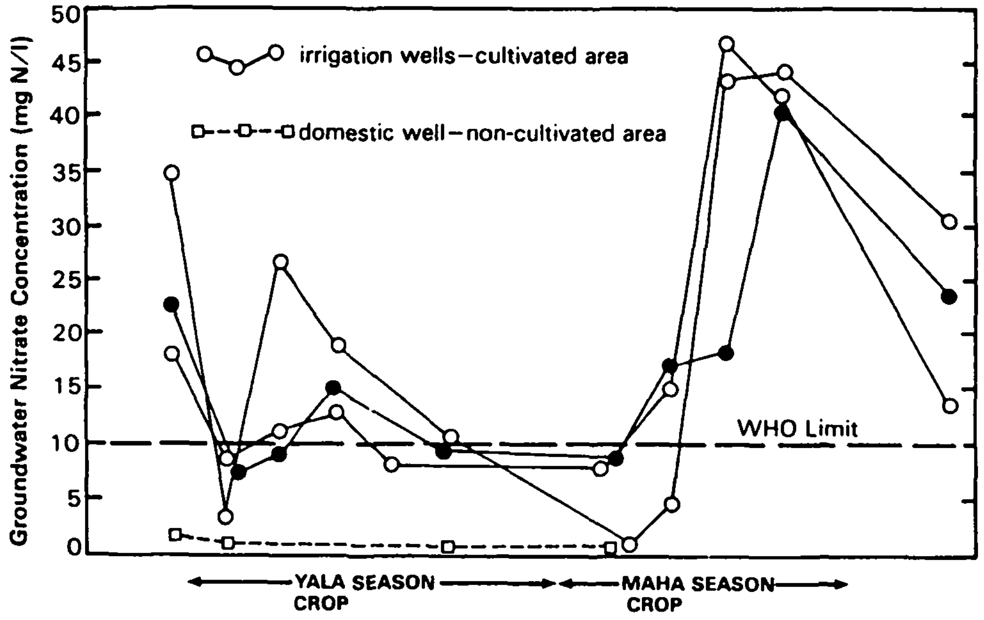


Figure 20 Seasonal nitrate variations in shallow sand aquifers in Sri Lanka in areas under intensive fertilized irrigation

Source: Lawrence and Kuruppuarachchi (1986)

In Europe, particularly in the countries with significant areas dependent on groundwater for public supply, there is great concern at present over nitrate concentrations, as revealed by the monitoring of supply sources. Nitrate is toxic to the very young when present in excessive levels in drinking water and can cause methaemoglobinaemia in bottle-fed infants at levels in excess of 10 mg l^{-1} NO_3-N (WHO 1984a,b).

In the U.K., 125 groundwater sources supplying 1.8 million people exceeded the WHO guideline value of 10 mg l^{-1} NO_3-N in 1983 and 1984 compared to 90 in 1980 and 60 in 1970 (DOE 1986). Uncertainties surround the prediction of likely maximum values in these areas, largely because of the difficulty of forecasting the behaviour of the large amount of nitrate presently in the unsaturated zone. Nevertheless, if agricultural practices remain unchanged, nitrate concentrations will eventually exceed 10 mg l^{-1} NO_3-N in most British unconfined aquifers and in the areas of lowest rainfall in eastern England concentrations are likely to exceed 20 mg l^{-1} NO_3-N (Foster et al. 1985). A trend similar to that of British rivers (Figure 21) and a French groundwater (Figure 22) is likely for other western European countries.

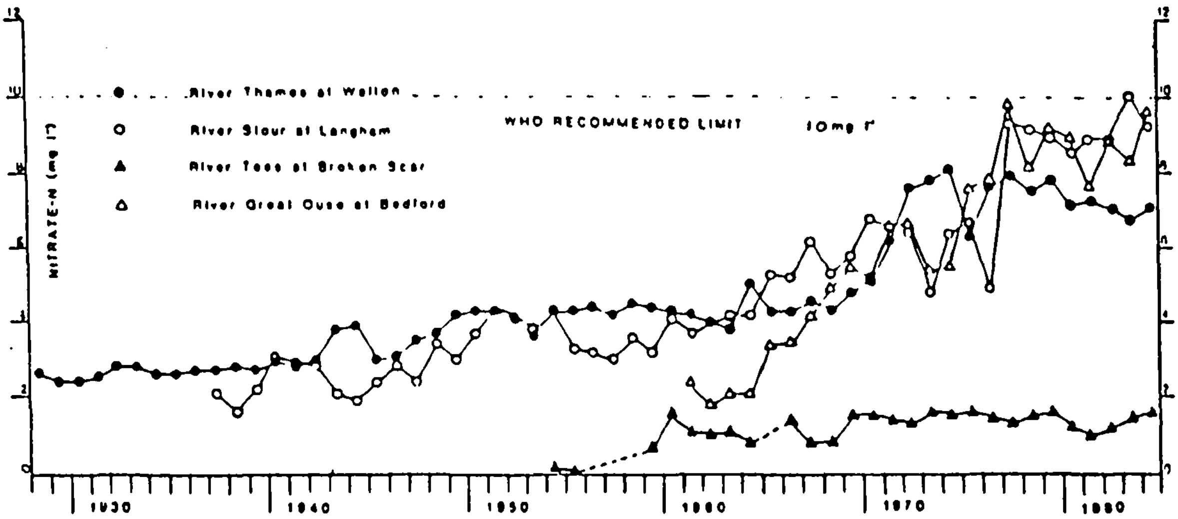


Figure 21 Long-term trends in nitrate concentrations in four British rivers

Source: Roberts and Marsh (1987)

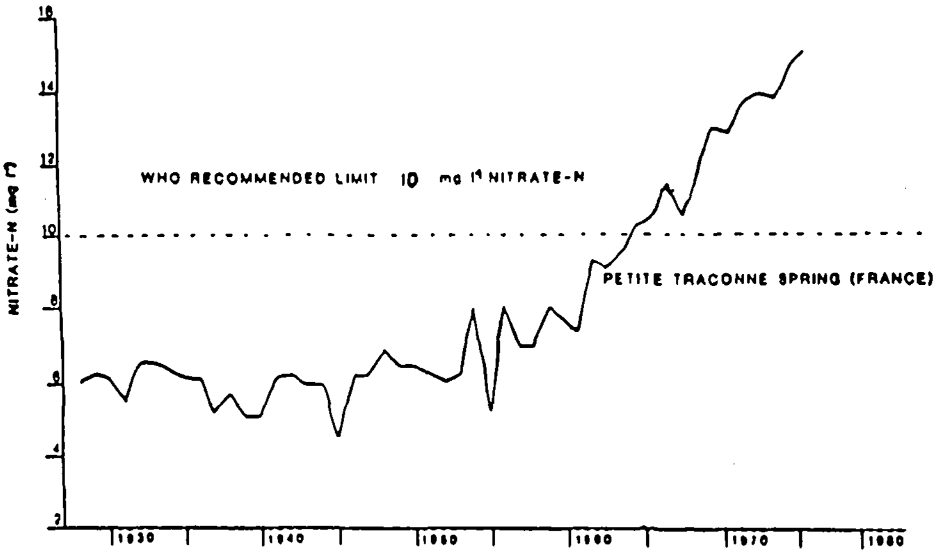


Figure 22 Trends in nitrate concentrations in the Petite Traconne Spring, Brie region, France

Source: Roberts and Marsh (1987)

The average nitrogen content for world rivers in pristine state has been estimated to 15 $\mu g\ l^{-1}$ NH_4-N, 1 $\mu g\ l^{-1}$ NO_2-N and 0.1 $mg\ l^{-1}$ NO_3-N (Meybeck 1982). Recent GEMS/WATER statistics (Table 34) indicate that in some regions of the world, particularly Europe, less than 10 per cent of the river stations can be classified as pristine. The median level of NO_3-N in all GEMS rivers outside Europe is 0.25 $mg\ l^{-1}$ whereas for European rivers it is 4.5 $mg\ l^{-1}$ NO_3-N (WHO/UNEP 1987).

Table 34 Ammonium and nitrate levels in GEMS rivers

Region	total number of stations	% coverage#	Percentage of rivers with values not exceeding (mg/l)				
			5%	10%	50%	90%	95%
NO3-N mg/l							
All GEMS stations	264	87	0.020	0.050	0.700	9.000	14.000
GEMS (not Europe)	175	83		0.025	0.250	1.400	
Europe	89			0.250	4.500	14.000	20.000
Asia & Oceania	82	87	0.018	0.035	0.350	2.000	4.000
N & C America	50	82		0.045	0.300	1.300	
South America	22	91		0.100*	0.200	0.500	
Africa	21	67			0.250		
NH4-N mg/l							
All GEMS stations	264	67	0.006	0.009	0.110	1.200	3.000
GEMS (not Europe)	175	56		0.005	0.070	0.600	
Europe	89			0.025	0.210	2.500	
Asia & Oceania	82	50		0.011	0.040	0.800	
N & C America	50	44		0.005*	0.015	0.200*	
South America	22	76		0.020	0.080	0.250	
Africa	21	53			0.020		

Notes

proportion of the stations effectively monitoring the variable

* approximate values

4.3.5 Pesticides

Only limited attention has been given to the leaching of pesticides from cultivated land, despite the fact that use of these compounds has increased greatly in recent years and new compounds have continually been introduced, particularly since the DDT ban in the late 1960s (Figure 23). The OECD countries (North America, Japan, Europe) rely heavily on herbicides and accounted for 82 per cent of the world sales in 1980. Insecticides are more commonly used (54 per cent of world sales) by the non-OECD countries; fungicides and miscellaneous pesticides are also mostly used by OECD countries (OECD 1985a). In developed countries, such as the U.S.A., insecticide use on crops has been very stable since 1964 and actually decreased since 1976; in contrast herbicide use has shown a 280 per cent increase from 1968 to 1981 (OECD 1985a,b). In rapidly developing countries pesticide use is also changing rapidly. For example, in Barbados according to Alleyne (1986), the shift from sugar cane cultivation to fruit and vegetables has resulted in a 400 per cent increase in pesticide importation from 1960 to 1984 and a dramatic broadening of the range of pesticides used. Since the early 1970s there has been a progressive shift to organophosphates, carbamates and, more recently, to synthetic pyrethroids. Organochlorine compounds, chlordane and dieldrin are still used but in very limited quantities for termite control.

Internationally, there is considerable variation and uncertainty regarding guidelines for permissible concentrations of pesticides in drinking water. The study of pesticides in water is made

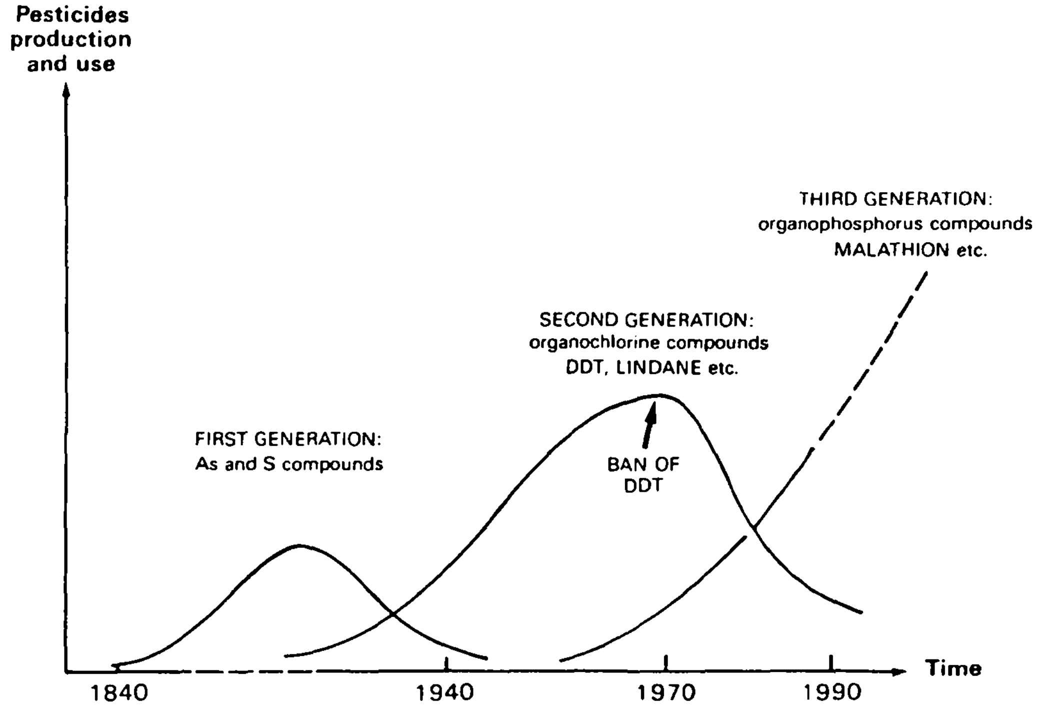


Figure 23 Historic trends in pesticide use

difficult because of the wide range of compounds in common use, many of which break down into derivatives, and because some of the compounds are highly toxic at concentrations below the generally achievable detection limits. These difficulties are accentuated by problems of sample alteration or contamination.

Pesticides are monitored routinely in a few of the stations selected for GEMS/WATER. Due to the variation in pesticide selection from country to country, the choice of variables differs as is shown in Table 24. Some of the results have already been given in Table 25. Drawing upon a much larger data base, an overview of typical monitoring results is compiled in Table 35 which also gives an indication of the pesticides used in different river basins.

The limited monitoring that has been carried out to date, together with a general consideration of the physical and chemical properties of pesticides in soils and water, suggests that the concentrations of some pesticides in groundwaters are likely to exceed guideline concentrations. However, if degradation occurs during transport, pesticide levels in groundwater may remain low (Lawrence and Foster 1987). More severe problems may be encountered in areas of intensive irrigation if both the hydraulic loading and pesticide application rates are high, and particularly where the area is underlain by shallow aquifers which also provide domestic water supplies. In developing countries this may be accentuated by the use of pesticide compounds which are no longer allowed in many countries, such as DDT, and by the use of heavy and irregular doses by untrained farmers.

4.4 Atmospheric Sources

Following the introduction of tall chimneys to disperse pollutant gases more widely, attention has shifted from local problems of SO_2 and particulate air pollution to issues arising from the effects of long-range transport of atmospheric pollutants and acid deposition. Emissions of SO_2 and NO_x from fossil fuel combustion are generally considered to be the main source of

Table 35 Occurrence of pesticides and PCBs in selected continental waters

Country	References	Site	Pollutants
USA	Oliver and Nicol 1984	Niagara River [1981-1983]	HCH : 12 ± 6.8 HCH : 1.7 ± 1.0 DDE : 0.2 ± 0.2 Chlordane : <0.5 PCB : 9.4 ± 4.7
Canada	Gummer 1980	14 rivers in the western region [1971-1977]	HCH : 3 - 9 HCH <1 2,4-D: <4 - 20 2,4,5-T : <2 - 3 DDT : n.d.
		Lake Superior [1980]	PCB : 0.9 ± 0.8
Argentina	Lenardon et al 1984	Parana River [1981]	HCH : 9 HCH : 9 Parathion : 22
Italy	Galassi and Provini 1981	Rivers Po and Adige [1977-1978]	HCH : 6.4 - 10.2 HCH : 4.3 - 5.3 DDT : 1.2 - 3.3 PCB : <20 - 100
France	Marchand et al 1986	River Loire [1982-1984]	HCH :13 - 21 DDT : n.d. PCB : 38 - 64
	Abarnou (pers. comm.)	River Seine [1984 - 1985]	HCH :10 - 50 PCB :30 - 1300
Holland	Duinker et al 1982, 1985	Rivers Weser and Ems [1976]	HCH : 1.9 - 5.9 HCH : 9.8 - 21.6 Dieldrin : 0.1 - 0.2 DDT : <1 Endrin : 0.1 PCB : 13
	Duinker and Hillebrand 1979	Rhine/Meuse Estuaries [1976]	HCH : 7 - 21 HCH : 9 - 13 Dieldrin : 4 - 13 Endrin : <1 DDT : <2 PCB : 20 - 400
	Wegman and Greve 1980	Rivers Rhine (R) and Meuse (M) [1977]	HCH : 20 (R), 10 (M) HCH : 20 (R), 30 (M) DDT, dieldrin : n.d. PCB :210(R),170(M)
India	Agarwal et al 1986	River Jamuna (Delhi) [1976-1978]	DDT : 240-560

the latter. Once in the atmosphere these are oxidised to their corresponding acids, sulphuric (H_2SO_4) and nitric acid (HNO_3) and /or converted to sulphate (SO_4^{2-}) and nitrate (NO_3^-) aerosols. Acidic substances are then returned to the earth's surface by either wet or dry depositional processes. Increasing levels of atmospheric deposition have been cited as the most probable cause of recent surface water acidification in the majority of affected areas.

Acidification of fresh waters was first observed in Sweden and Norway but is now reported in eastern North America and throughout much of Northern and Central Europe. Recently acidified lakes and streams are generally found in areas underlain by non-calcareous bedrock and siliceous sandy soils. Such acidified waters typically have a low pH (4.5-5.5), high transparency, low levels of organic acids and elevated levels of dissolved aluminium (Al) with SO_4^{2-} as the dominant anion. In contrast, surface waters unaffected by atmospheric sources are generally dominated by Ca^{2+} and HCO_3^- and have pH levels above 5.5. Regional surveys of lakes have been conducted in a number of countries in order to determine the geographical extent of fresh waters sensitive to acidic deposition. Results for eastern North America are summarized in Table 36. Lakes in eastern Canada are found to be particularly susceptible with more than 90 per cent of lakes sampled having alkalinities below 0.2 meq l^{-1}.

The observed increase in dissolved Al concentrations in acidified lakes and streams has caused particular concern in view of the toxicity of this element to aquatic life. Adverse effects in fish have been reported at concentrations above the range 100-220 μg l^{-1} (Driscoll 1985). Such levels are commonly found in acidic lakes and streams (Wright et al. 1980). The possibility that increasing acidity mobilizes other trace metals from soils and lake sediments, for example Cu, Co, As and Hg, is also currently receiving attention.

Table 36 pH and alkalinity in North American lakes

	pH Percentage				ANC Percentage			
Country/Region	Sample no.	<5.0	<5.5	<6.0	Sample no.	<0 ueq/l	<40 ueq/l	<200 ueq/l
USA:								
The Northeast	7096	3.4	8.6	12.9	7096	4.6	17.0	60.0
(a) Adirondacks	1290	10.0	19.9	26.6	1290	10.7	31.3	70.5
(b) Poconos/Catskills	1479	0.8	5.7	7.8	1479	5.3	12.2	38.7
(c) Central New England	1483	1.7	7.8	12.9	1483	2.4	16.4	67.6
(d) S. New England	1318	5.0	10.0	14.6	1318	5.0	19.6	57.3
(e) Maine	1526	0.5	1.6	4.8	1526	0.5	7.6	66.8
Upper Midwest	8501	1.5	3.6	9.6	8501	1.7	11.1	41.4
(a) N.E. Minnesota	1457	0.0	0.0	1.4	1457	0.0	1.9	57.0
(b) Upper Peninsula of Michigan	1050	9.4	13.6	17.7	1050	9.8	18.3	41.7
(c) Northcentral Wisconsin	1480	2.1	11.1	27.7	1480	3.1	37.0	56.7
(d) Upper Gt. Lakes Area	4515	0.0	0.1	4.5	4515	0.0	3.9	31.3
The Southeast								
(a) S. Blue Ridge	258	0.0	0.0	0.4	258	0.0	0.8	34.3
(b)Florida	2098	12.4	20.6	32.7	2098	22.0	32.9	55.1
Canada								
NW Ontario	1080	0	1	4	1078	<1	4	40
NE Ontario	1820	6	10	20	1805	9	24	51
S Ontario	1619	2	8	28	1578	3	32	83
Quebec	434	3	12	30	429	1	55	90
Labrador	198	<1	2	20	182	0	43	95
New Brunswick	84	7	15	36	81	11	51	96
Nova Scotia	232	39	63	82	198	51	93	99
Newfoundland	270	3	14	44	176	7	68	94

ANC = Acid Neutralising Capacity

Adapted from: Linthurst et al. (1986); Jeffries et al. (1986)

Two different approaches have been widely used for the assessment of trends in lake water pH:

- comparison of historical and recent data on pH, alkalinity and sulphate concentrations;
- the use of fossilized diatom assemblages preserved in lake sediments for lake water pH reconstruction.

Although pH is measured as a basic variable within the GEMS/WATER network, the data sets currently available are of insufficient length to detect significant changes in pH beyond normal seasonal fluctuations. Evidence of surface water acidification has been obtained from the analysis of extended time-scale pH records for selected lakes in Scandinavia, the U.K., the Netherlands and eastern North America. However, the best evidence for surface water acidification is provided by the second approach. Analyses of diatom assemblages have clearly demonstrated that some lakes in acid sensitive regions have undergone acidification during the past 100 years. Decreases in pH of 0.5-1.5 units are particularly evident in poorly-buffered, low alkalinity lakes having pre-1800 pH values between 5 and 6. Diatom data for a number of lakes in the Adirondack Mountain region of New York are presented in Table 37, together with supporting information on water quality and declining fish populations.

Table 37 Measured pH, diatom-inferred pH and fish populations in selected Adirondack lakes

Lake	Measured pH		Inferred pH		Fish Survey data	Comments/Conclusions
	Year	pH	Year	pH		
Big Moose	1948 1965 1971 1981 1982	6.0 5.2 5.5 5.3 4.9	pre-1800 present	5.8 4.9	10 species present in 1948, declining to only 5 - 6 species since 1962	All data are consistent and indicate acidification
Upper Wallface	1963 1975 1979	5.6 4.9 5.0	pre -1800 present	5.1 4.7	Brook trout moderately abundant in 1963-68, gone in 1975	All data are consistant and indicate acidification
Honnedaga	1975 1982	4.9 4.8	pre -1800 present	6.1 5.2	Lake trout became rare and emaciated in early 1950s, last collected 1954; brook trout declined in mid 1960s and were very rare by the mid 1970.	Fish and diatom data indicate acidification but changes appear to have occurred gradually
Deep	1954 1979	4.7 4.6-4.7	pre 1800 present	5.0 4.8	Brook trout present, moderately abundant in 1954, absent in 1964; no survival of stock fish since 1964	Fish and diatom data indicate slight acidification

Adapted from: NRC (1986)

Degradation of aquatic ecosystems as a result of acidification is generally well documented. The most obvious effects are on fish populations but adverse impacts on primary producers, invertebrates, aquatic birds and amphibians are becoming increasingly apparent. Moreover, mobilization of potentially toxic metals, such as Al, Cu, Pb, Hg and Cd, which may result in the contamination of drinking water supplies has lead to concerns for possible health risks. However, to date no adverse effects in humans due to acid deposition have been detected.

Increasing anthropogenic emissions of SO_2 (Figure 24) in a number of rapidly industrializing nations, have given rise to relatively high levels of SO_4^{2-} in precipitation in areas outside North America and Europe. Levels in precipitation in excess of 1.5 - 2.0 mg l^{-1} are observed in the following regions; (i) Eastern China, Japan and the Philippines, (ii) South Africa and (iii) the east coast of South America from Rio de Janeiro to Sao Paulo (Wallen 1986). The occurrence of acid sensitive soils in some of these areas indicates that problems of water and soil acidification may become apparent in the future.

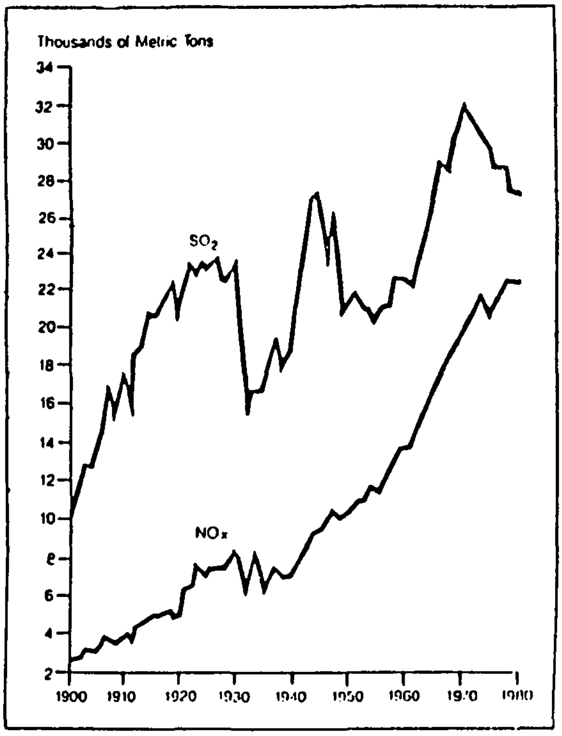


Figure 24 Global emissions of SO_2 and NO_x

Source: WRI (1986)

Potential impacts of acid deposition in tropical and subtropical regions were reviewed in 1986, as part of the SCOPE programme (SCOPE 1988). It was concluded that widespread acidification has not yet emerged as a major problem in these regions, with the possible exception of China. In northern China, where alkaline soils tend to dominate, surface waters are generally well buffered and therefore insensitive to acidic deposition. High levels of alkaline particulate matter in the atmosphere ensure that the pH of precipitation is generally over 6.0. In southern China, however, soils are more acidic, poorly buffered and therefore at greater risk from acidification. The pH of precipitation is lower, typically between 4.5 and 5.5. Sulphate deposition rates are extremely high in China, exceeding those in eastern North America and represent a major ecological concern, particularly in the south where low alkalinity lakes are present (Galloway et al. 1987).

through water intake are probably few (see Figure 26). Major industrial fires caused the pollution by pyrocatechine of the Rhone river in June 1985 downstream of Peage de Roussillon (60 tonnes of fish were killed and the river water downstream was unfit for drinking in 69 villages for at least 2 days) and the Rhine river pollution in November 1986 by miscellaneous products (the Sandoz accident) which also resulted in similar problems on a greater scale (Com. Int. du Rhin 1988). More recently, spillage from an oil tanker caused major pollution in the Ohio river in January 1988 which also resulted in the closure of water intakes for drinking purposes in some places. A major nuclear accident on a large river, although unlikely, would probably cause a complete and direct deterioration of downstream waters to the sea and indirect contamination (through the atmosphere) at a regional scale which would last much longer than any other type of accident, due to persistent sediment and groundwater contamination.

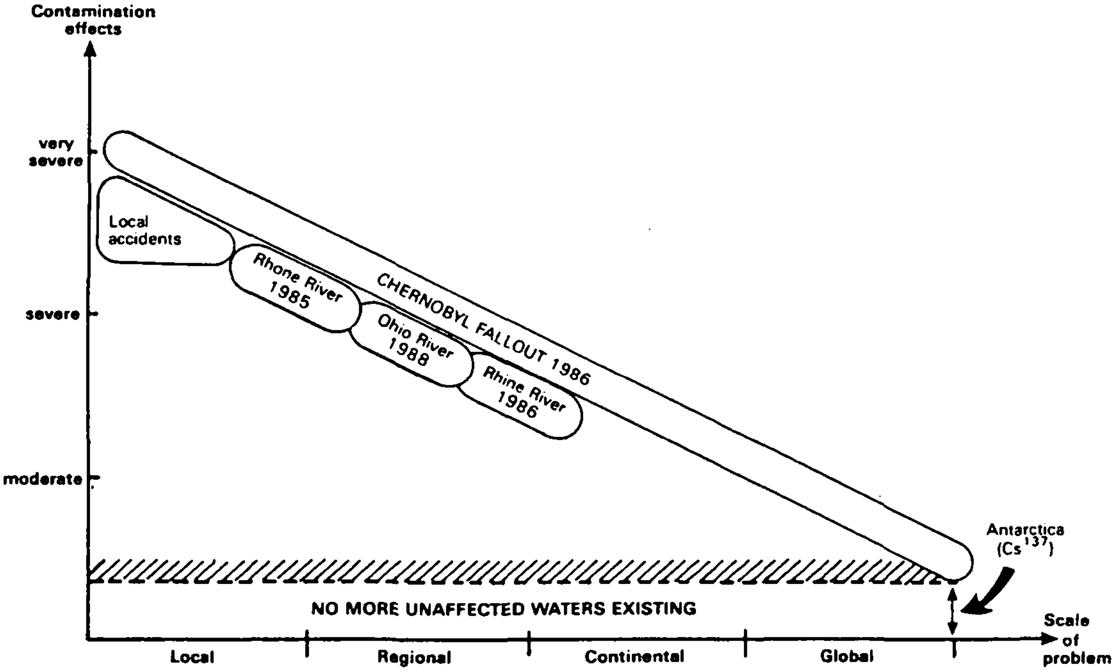


Figure 26 Occurrence and importance of accidental water pollution

5.1 Global Trends in Water Pollution

Today's most important problem areas are summarized below in order to highlight trends in water pollution and the need to measure and control their impact on the environment and on human health. The present global pollution assessment report has revealed, among other findings, that the concern over pollution issues varies not only geographically and thematically, but also with the socio-economic situation of a country or region.

For the purpose of generalizing pollution trends, countries may be categorized into one group of highly industrialized countries, another of moderate-to-rapidly industrializing countries, and a third group of countries at a low level of industrial activity with a predominantly traditional agricultural structure (WHO 1985). In countries with a low level of development, including the least-developed countries, point-source pollution is only a marginal problem mainly due to the lack of sewerage networks in the cities. Although water pollution within city areas may be severe, water resources in general do not suffer greatly from pollution. This, however, is not the case in areas where mineral resources are exploited on a large scale. Mining waste deposits and acid mine drainage often have far-reaching pollution impacts on surface and groundwater resources, due to the large scale of the operations.

Examples of the severity of organic pollution in relation to the spatial scale of contamination of world waters with respect to pathogens, oxygen balance, nutrients and eutrophication and nitrates are given in Figure 27. Very severe pathogen pollution causing infant deaths occurs in many developing countries, particularly when water availability is low. Many streams and rivers in central and tropical South America, the Indian Sub-continent and South East Asia illustrate the maximum evolution of organic contamination for a given basin size, as indicated by faecal coliforms, BOD or O_2 and nutrient levels. Although very poorly documented so far, African rivers are likely to present the same situation. The river Ganges in some stretches is probably the most polluted river of its size due to the high population density along its banks and in the catchment; a major action plan is now under way to reduce this pollution. In contrast, the Mississippi river shows evidence of only limited contamination which is contained by the waste treatment plant that was built 20-30 years ago, whereas the Amazon can still be considered to be in a pristine state.

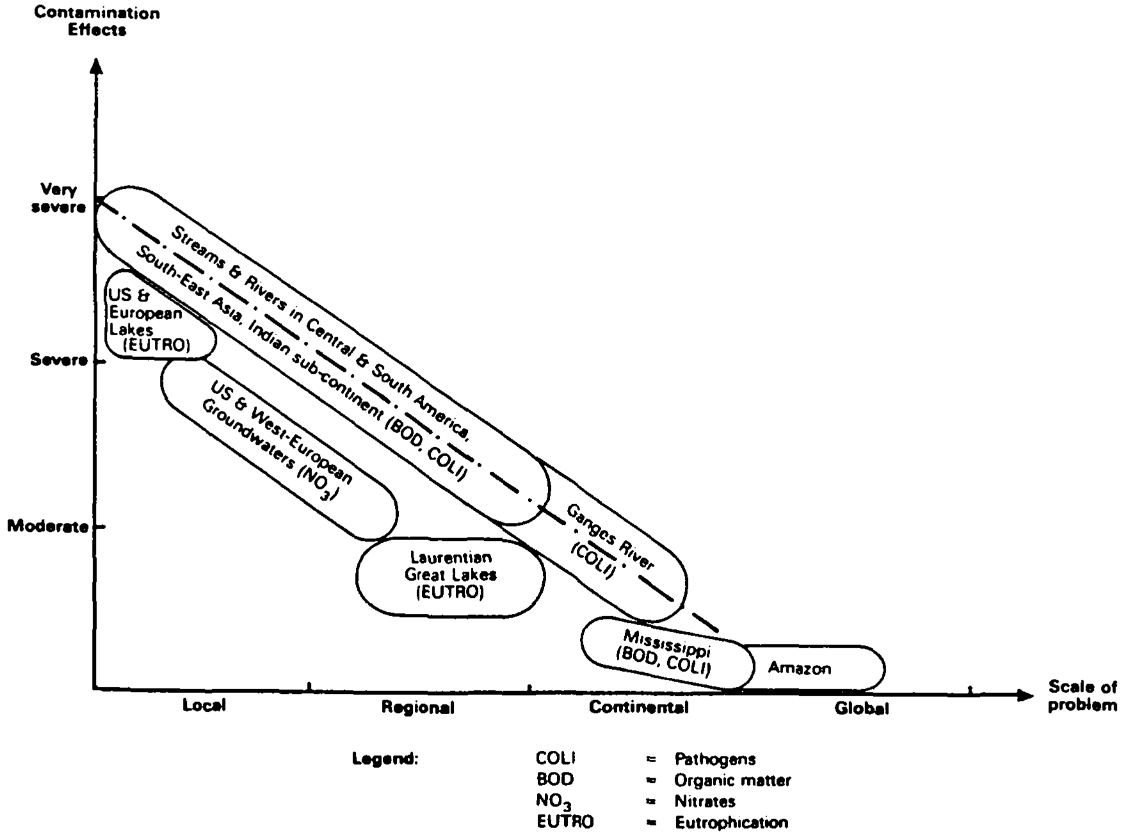


Figure 27 Occurrence and importance of organic water pollution

Eutrophication, which is often directly connected to organic waste, started about 30 years ago and has already badly affected many small lakes in Europe, U.S.A. and, more recently, in Asia. In Europe the problem is also affecting small and medium-sized reservoirs built in agricultural regions where nutrient sources are multiple and sometimes diffuse. In developing countries such as China, 25 per cent of major Chinese lakes are already eutrophic or hypereutrophic (Hou Ranjie and Zhu Xuan 1987). Increased nitrate levels in ground waters is currently a severe problem in many western European countries as well as in the U.S.A. In many places, the WHO guideline value for drinking water quality has already been exceeded. There are also groundwater problems in arid and semi-arid areas with nitrate concentrations, and where no alternative water sources are available.

Salinization resulting from evaporation has always been associated with irrigation, but has now reached a regional to continental scale in ground waters in Sahelian Africa and in the arid belt from the Middle East to India. In many coastal aquifers where salt intrusion has been enhanced by overpumping, the water has become unfit for any use. In continental rivers the presence of salts is mainly due to mining (mine tailings wastes) and has already resulted in severe contamination in many places such as in the Alsace Rhine aquifer, the Weser and the Rhine rivers. In Alsace, Cl^- has exceeded WHO guidelines, whilst in the Rhine the water salinity causes major damage to the vegetable and flower crops of the Netherlands. Evidence of slight to marked salt increases in waters can now been found in many populated and developed regions, although levels are usually 10 to 50 times less than any guideline (e.g., Lake Geneva and Laurentian Great Lakes, Figure 28). Deforestation can be considered to have affected surface waters on a larger scale than salinization. However, the resultant increase in levels of suspended matter is sometimes counter-balanced by river damming which retains most of the particulate matter. Dams can also decrease water quality by causing salinization, retaining nutrients that were previously needed for irrigation and encouraging water-related diseases.

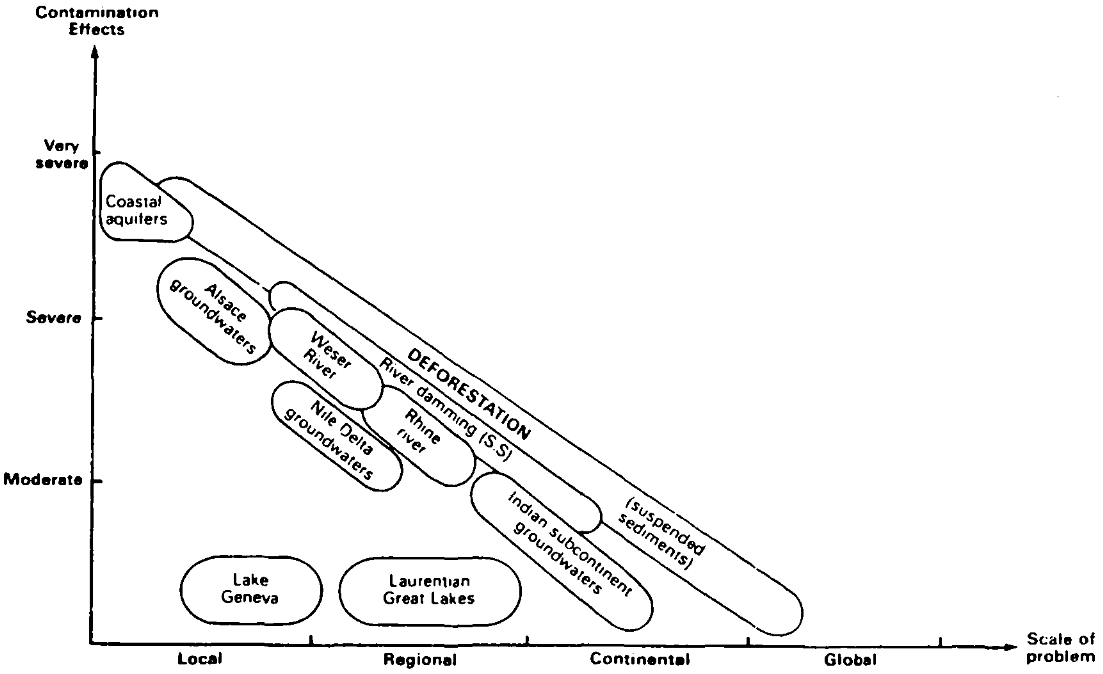


Figure 28 Occurrence and importance of salinization and of sediment loads

Metal contamination of water resources probably started with major Roman mining operations and evidence of such pollution can be found in some Welsh lake sediments and also in Lago di Monterosi near Rome (Hutchinson 1970). Examples of the worst deterioration in water quality can be found from local to regional scales (Figure 29). Pollution of the Jinzu river by cadmium caused the well known "Itai-Itai" disease. The Elbe river is still severely contaminated with cadmium and mercury, and the latter has polluted some Canadian lakes downstream from chloralkali plants. The Sudbury smelter in Canada has long been considered one of the largest single-point sources of metal pollution which has contaminated, through atmospheric transport, extensive areas of the Ontario and Quebec provinces. At the global scale, lead levels have increased in Greenland and even in Antarctic ice cores. Scandinavian and North American rivers and lakes are now affected by acid deposition which results in marked increases in dissolved aluminium. This problem is not yet recorded in developing countries, but could emerge as a result of increased fossil fuel burning for power production.

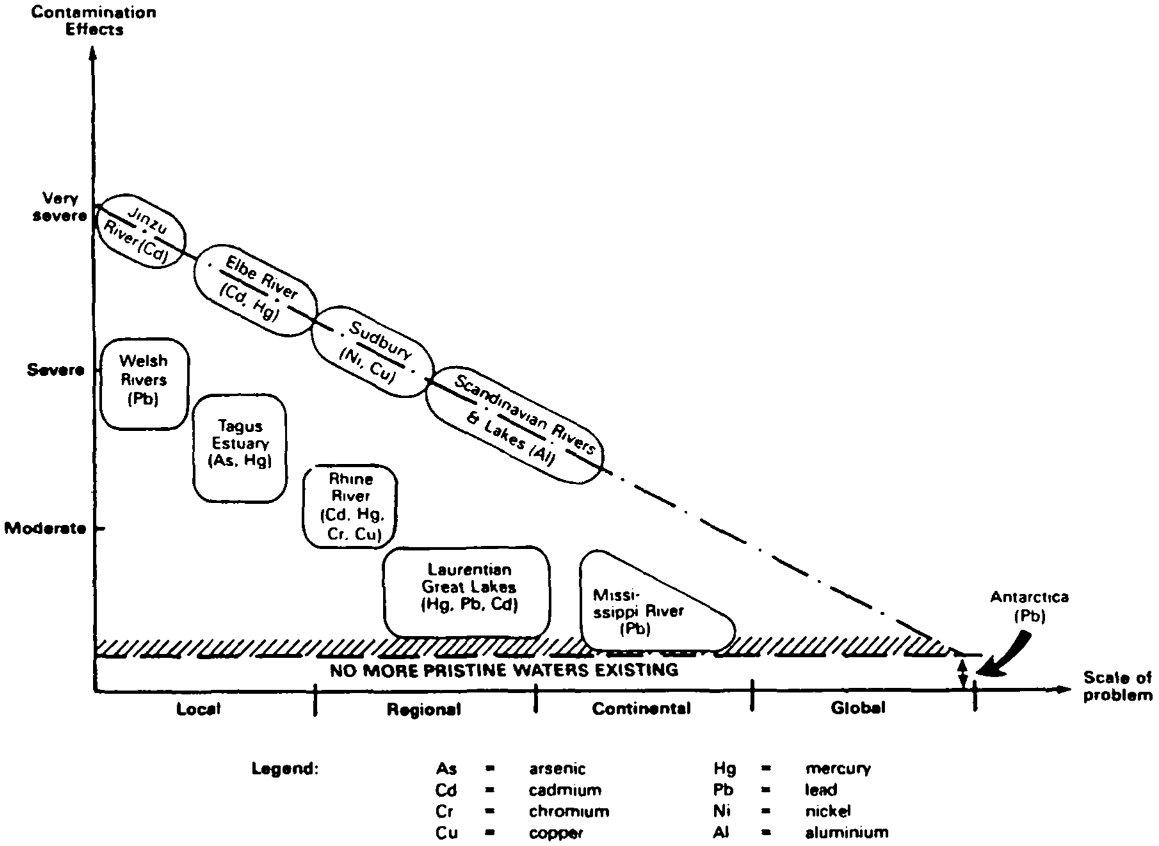


Figure 29 Occurrence and importance of heavy metal water pollution

Contamination by synthetic organic micropollutants is a more recent phenomenon, although in some places of major concern. It is difficult to assess water quality on a global scale for this category of contaminants, due to the lack of appropriate surveys. Even in developed countries, such as in Europe and North America, state surveys are still insufficient to draw general conclusions. The number of critical substances is rapidly increasing as new substances replace older ones. Therefore, a major uncertainty exists in Figure 30 relating to the maximum extent of contamination on a continental scale. Other scales are much better documented - local incidents in rivers and ground waters (such as Zurich, Long Island N.Y. and many others) are known to have caused very severe pollution, although the related casualties have not been reported. On investigation many rivers are found to be contaminated, such as the Jamuna river near Delhi (DDT) and the Seine and Rhine rivers (PCBs, chlorinated solvents, chlorophenols, volatile aromatic compounds). Pesticides are also likely to be found in many South-East Asian and African rivers. Trace contamination of large water bodies is now reported, such as in Lake Superior, and is

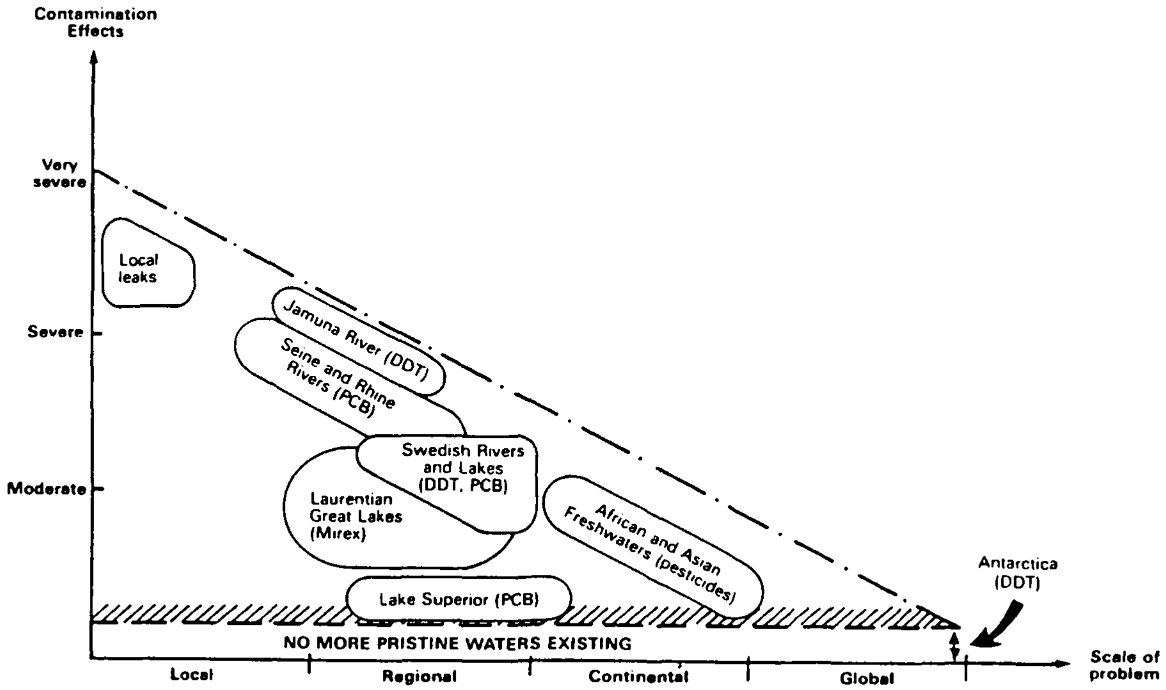


Figure 30 Occurrence and importance of organic micropollutant water pollution

generally attributed to atmospheric transport of pollutants. Improvements in water quality with respect to organic micropollutants is evident in many places at various scales, for example, Lake Geneva (DDT decrease), the Laurentian Great Lakes (Mirex insecticide), and Swedish waters and their aquatic wildlife (DDT, PCB).

5.2 Control Measures

Today advanced countries (mainly those in Europe) have experienced severe pollution and have undertaken a series of control measures designed to mitigate and curb water pollution. These measures include sewage disposal regulations, construction of city sewerage schemes, wastewater treatment installations, industrial effluent treatment and recycling, substitution of harmful or deleterious consumer products (non-biodegradable detergents, phosphates, alkyl lead) and banning of hazardous pesticides (DDT) and industrial chemicals (PCBs). Decreases in Pb in sediments in the Gulf of Mexico indicate decreases in Pb levels in the Mississippi watershed due to reductions in Pb emissions from automobiles.

The need for the control of transboundary emissions of SO_2 and NO_x is now recognized by the majority of industrialized nations. Acid deposition not only causes adverse impacts on freshwater quality but is also implicated in forest damage and deterioration of building materials. Reductions in SO_2 emissions have already been achieved in some of the industrialized countries and these are expected to continue in the future. However, emissions of NO_x have not generally declined and international agreements for their reduction are not as far advanced as those for SO_2. It may therefore be expected that nitrogen compounds will play a greater role in water acidification in the future. Greater emphasis on the contribution of NH_4^+ deposition is also likely, especially in regions where emissions of NH_3 from agricultural sources are significant.

Major water pollution threats exist today in industrializing countries with rapidly growing populations such as Brazil, China, India, Indonesia, Mexico and Nigeria, where pollution sources and demands upon water resources are expanding. Only 10 out of the 60 countries in this category have established effective laws, regulations, and enforcement infrastructures to cope with new and growing pollution problems (Helmer 1987). The appearance of traditional and modern types of water pollution, which occurred over 100 years or more in Europe, occur within one generation in developing countries, as shown in Figure 31. Achieving control over pollution issues in these countries has, therefore, become a question of ecologically and economically sustainable development. In these developing countries urban air pollution has already had obvious impacts in several large urban agglomerations, whereas the deterioration of the surrounding surface and groundwater quality is less visible, partly due to inadequate surveillance programmes. However, the consequences are no less costly to remedy.

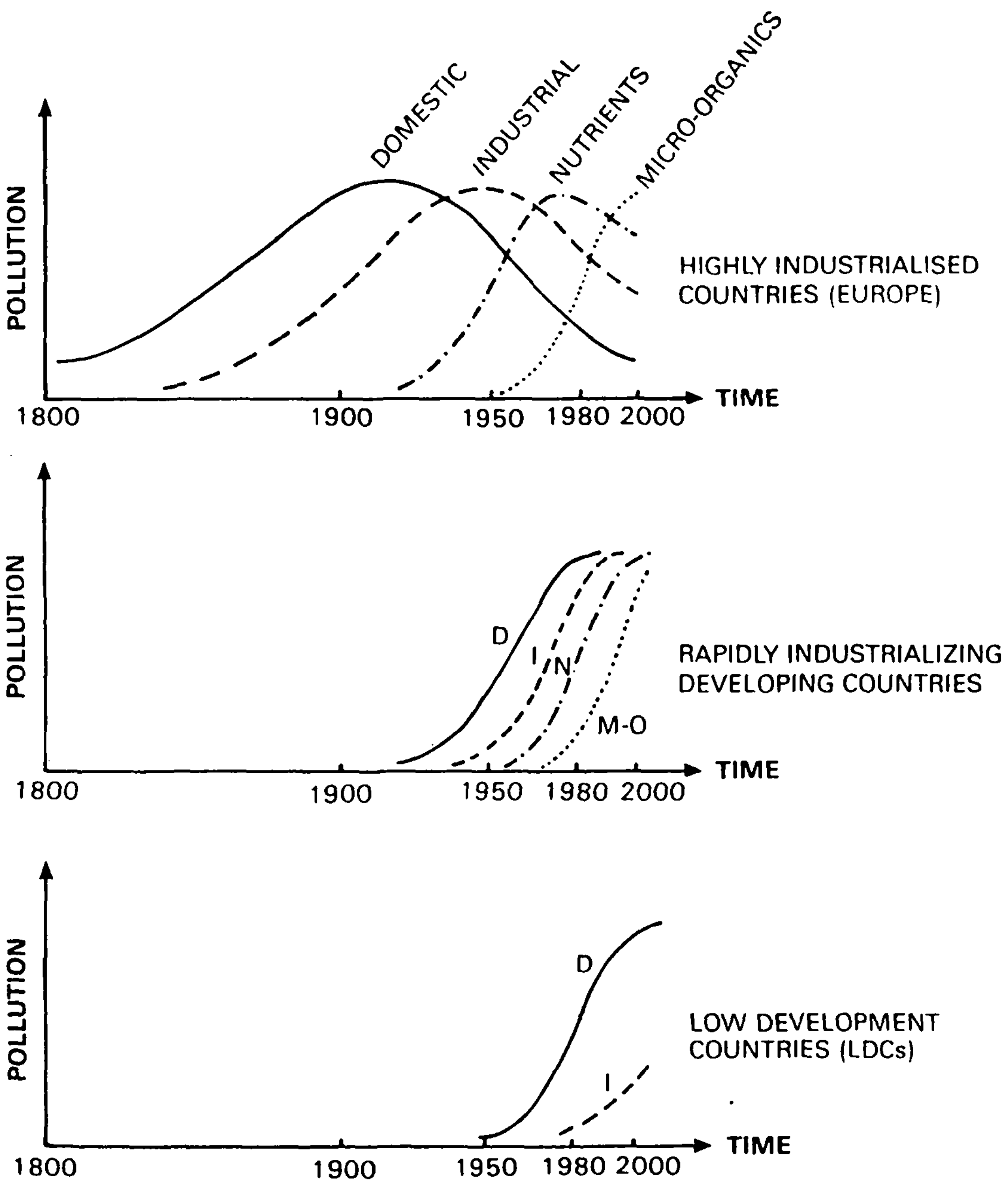


Figure 31 Evolution of water polution problems in countries according to development pace and status

Collection and treatment of wastewaters and control of effluents are not alone sufficient to combat water pollution. The time period between the introduction of a new chemical substance and its environmental levels being brought under control has always been rather long. For example, the complete cycle between the invention of a new product such as DDT and its environmental control was up to 30 years. The simultaneous appearance of different pollutants (heavy metals, organic micropollutants, etc.) requires the initiation of much faster responses by the relevant environmental protection authorities. Furthermore, innovative control mechanisms need to be imposed or made economically attractive. Major reductions in water demands and effluent discharges have been achieved in this way in many industrial and manufacturing sectors. Re-use of water and rational water quality management, together with a policy for the safe use of chemicals, are indispensable for the maintenance of water quality at the levels necessary for the water users.

In principle, measures are available to combat salinity and waterlogging. For example, the use of micro-irrigation techniques can greatly reduce infiltration and therefore avoid the problem of rising water levels. Their effectiveness as a preventive measure against waterlogging is evident from the countries where they have been extensively adopted, such as Israel. Where problems of waterlogging and salinity are already present, more efficient irrigation by itself is not adequate as a remedial measure. Instead, leaching out of salts by excess irrigation combined with effective and rapid downward drainage are required. In the case of soda salinization, chemical treatment of the soil may also be necessary. Examples of very effective control of waterlogging and salinity are hard to find. Prevention of water quality deterioration from irrigation requires the whole combination of measures, otherwise the salinity problem is merely pushed further along the hydrological cycle. Combating soil salinity by leaching from excess irrigation, for example, transfers the salt to the underlying ground water. Implementing extensive drainage measures may successfully prevent waterlogging and salinity, but the saline drainage water requires disposal and can cause water quality problems when returned to rivers. Truly comprehensive and effective drainage measures may therefore only be possible where highly saline effluent can be released into the sea.

Only radical changes in agricultural practices could reverse the overall trend in nitrate pollution; these would involve significant losses in productivity and the recovery would be over a long term (Foster et al. 1985). Current proposals for groundwater protection policies under consideration envisage the changing of agricultural practices in areas defined by groundwater recharge to public supply sources. Many of the management approaches available in Europe and North America are, however, not applicable in the institutional and financial framework of the developing countries. Appreciation of the potential impact of intensive agriculture on shallow ground water in tropical areas is relatively recent, but problems are likely to become increasingly acute, more widespread and difficult to control.

5.3 Emerging Global Water Pollution Issues

These issues already exist to a small degree in some countries but will become significant on a global scale in the future.

5.3.1 Accidental Pollution

Major industrial accidents resulting in the large-scale contamination of vital water resources will probably occur with increasing frequency. The large number of manufacturing, production and storage facilities along river banks in many countries leads to a high probability of accidental spillage. In view of the socio-economic constraints under which most companies operate in the developing countries, there is little realistic hope that effective safeguards against such accidents will be introduced in the near future. Consequently, the possibility of major accidents must be taken into account by the responsible water quality management authorities and procedures for rapid action established. These could include administrative safety regulations at a national and international level (e.g., through inter-state river agencies or any other appropriate agencies), monitoring and contingency plans and the creation of emergency clean-up and pollution containment services.

With respect to the consequences of accidental spillage into water resources, rivers generally recover more easily than static waters due to the flushing effect of the river flow. Although a pollutant wave could destroy all higher forms of aquatic life in a section of the river, restoration is usually achieved quite rapidly. In the case of contaminants infiltrating accidentally into aquifers, the consequences are less visible, but may be more severe and longer-lasting. Residence times of ground water are much longer and the exchange processes with water-bearing geological strata are slower. These phenomena together require a period of years to recover. Special studies are, therefore, recommended to develop technological methods for accelerated groundwater clean-up and for the rapid containment of pollutants in case of an accidental spill.

As a long-term strategy, water authorities must exert pressure for the establishment of environmentally oriented practices for industrial plant safety and for accident prevention. The occurrence of major accidents in all countries is likely to increase. Although industrial accidents are often the only obvious sign of pollution inputs, they are generally more severe in their immediate consequences and may serve as the life-threatening disaster which triggers enough public awareness over environmental issues to make more profound and lasting pollution control measures possible.

5.3.2 Land disposal and mine tailings

The disposal of mine tailings and industrial and municipal waste substances in landfills without adequate environmental safeguards has developed into a hazardous source of pollution. These landfills generally date back to a time when no regulations existed in either the industrialized or the developing countries. Such sources of pollution will become more and more significant as traditional point sources of pollution come under control. At present the annual quantities of heavy metals disposed to land as a result of production and consumption (Nriagu and Pacine, 1988) are equivalent to, or up to, eight times greater than the total river fluxes to the oceans.

5.3.3 International transport of wastes

The transfer of solid and liquid wastes, particularly from industrialized to developing countries, may lead to severe and unpredictable water pollution problems in the future. This practice is considered unacceptable and efforts to discourage it will be required.

5.3.4 Water disinfection by-products

Drinking-water chlorination has been enormously successful for disinfection and should be continued. Nevertheless, a threat of contamination from the formation of halogenated organics and other toxic compounds has been recognized in recent years. The potential carcinogenicity of compounds such as trihalomethanes formed during the chlorination of surface waters containing organic substances (e.g., humic and fulvic acids) has raised concerns. Assessments of health risks from such compounds relative to the recognized benefits from chlorination should be undertaken.

5.3.5 Deterioration of biogeochemical cycles and water quality

The magnitude of anthropogenic activities influencing the environment has increased dramatically during the last few decades and has affected terrestrial ecosystems, the freshwater and marine environment and the atmosphere. Large-scale mining and fossil fuel burning have started to interfere measurably with natural hydrogeochemical cycles resulting in a new generation of environmental deterioration and pollution problems. The scale of socio-economic activities — including urbanization, industrial operations and agricultural production — has reached a level where it interferes not only with natural processes within the same watershed, but has an impact on water resources and their quality elsewhere. As a result, a very complex picture of interrelationships between socio-economic factors and natural hydrological and ecological conditions emerges. Some of the issues emerging as the most relevant ones for global water quality are the following:

- Pollution from fossil fuel burning, industrial production, mining and smelting, and agricultural practices has contaminated the atmosphere on a global scale. This has led in turn to significant acidification of lakes and increasing contamination of surface waters (even in remote areas) with toxic chemicals. Such atmospheric pollution is also predicted to cause future climate warming.
- The rapid increases in water use, particularly the ground water withdrawals observed in semi-arid and coastal zones, will lead to widespread salinization and other water quality problems in future years.
- Large-scale deforestation in river basins, such as the Amazon, results in erosion of irreplaceable top soil and substantive nutrient losses.
- The shift of pollution problems one or more steps down the hydrogeological cycle, rather than solving them at the point of occurrence, has emerged as a major wide-scale issue. Examples include the Alsacian potassium mining wastes which when dissolved and discharged into the Rhine River rendered it unfit for use in greenhouse market-gardening in the Netherlands, the downstream export of salts from irrigation farming in Arizona to Mexico and the eutrophication of lakes and marine coastal waters from increased river nutrient loads.
- Damming of major rivers, such as the Nile, has led to decreased sediment transport and increased nutrient retention so that sediments and nutrients are lost to downstream irrigation areas and estuarine fisheries.
- The widespread destruction of wetlands eliminates a natural filter and biodegradation mechanism for many common pollutants.

5.4 Improvement of Water Quality Assessment

Data collection and evaluation for this assessment was hampered by a lack of data for certain geographic regions and variables. For example, the geographic coverage of the GEMS/WATER network is largely determined by the co-operation afforded the project by the countries and their participating institutions. Information from most Eastern European countries has not been made available. African water resources are very rarely monitored for their quality, and water quality surveillance programmes are only operational in some countries in Latin America and South-East Asia.

No routine monitoring data on organic micropollutants exist for most of the world's freshwater bodies or ground waters. Many aquifers are monitored locally but little integrated information on groundwater quality exists on a regional scale.

There are many difficulties involved in the sampling, preparation, analysis and interpretation of heavy metals and persistent organic micropollutants in the water phase. Suspended particulate matter and sediments should thus be used for reconnaissance surveys and routine monitoring of these pollutants. Most metals and many of the organics are attached to particulate matter, for which they tend to show a much greater affinity than to the liquid phase. Aquatic biota can also be monitored, since some organisms tend to concentrate and also integrate a number of organic and inorganic contaminants. Aquatic bryophytes (mosses) and mussels have already been used for this purpose in some countries.

Another new direction in the monitoring of aquatic toxicity is the use of laboratory and/or *insitu* bioassays. These are relatively simple and inexpensive and have the potential to provide an integrated measure of the combined or synergistic effects of micro-organics, metals and other unidentified contaminants.

In most developing countries neither the necessary laboratory instrumentation nor the highly specialized personnel are available to monitor micropollutants accurately. However, simple integrative measurements of categories of pollutants, such as specific conductivity for ions or dissolved oxygen and oxygen demand for organic pollution, can be carried out. Total chlorinated hydrocarbons, for example, could serve as a general indicator of water pollution until such time when detailed analyses become possible.

Many of the heavy metal and trace organic data from past years are unreliable due to sample contamination. Water containers, pumps and filtration units which do not release any of the substances which are to be measured must be used. Utmost care in sampling is required, particularly for ground waters where dissolved pollutants are present at low concentrations.

The reliability of the analysis of water is another important step in the global assessment of water quality. For many variables the intercomparability of analytical methods is not always possible and the essential analytical quality control is not always performed.

Trace metals are at present inadequately researched with regard to their fate and behaviour in the aquatic environment. More insight is required regarding their behaviour under different environmental conditions (pH, redox potential, salinity, uptake and metabolism in biota), especially for the more unstable forms (organic metal compounds, dissolved metals). This knowledge is an indispensable prerequisite for building realistic models of their pathways and behaviour.

Much research is under way on the identification and quantification of various organic micropollutants. More studies are needed, however, on the absorption and degradation of pesticides, industrial solvents and PCBs, particularly once they are leached into the unsaturated and saturated zones of ground water. Field and laboratory research is needed to verify the factors determining the attenuation of these pollutants and their microbial degradation for each type of aquifer.

Better understanding of the basic biogeochemical processes and interactions between particulate and dissolved forms of pollutants, biota and sediment is required to assess the fate and pathways of pollutants in the aquatic environment. Models need to be developed for this purpose and reliable data generated to verify their validity and practical relevance. Although adequate models for biodegradable organic matter and oxygen balance in rivers exist, there have been only a few models generated to describe the fate of metals and organic micropollutants. Ground water models which describe the transfer of miscible and immiscible pollutants into the microporous matrix of aquifers are also lacking.

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