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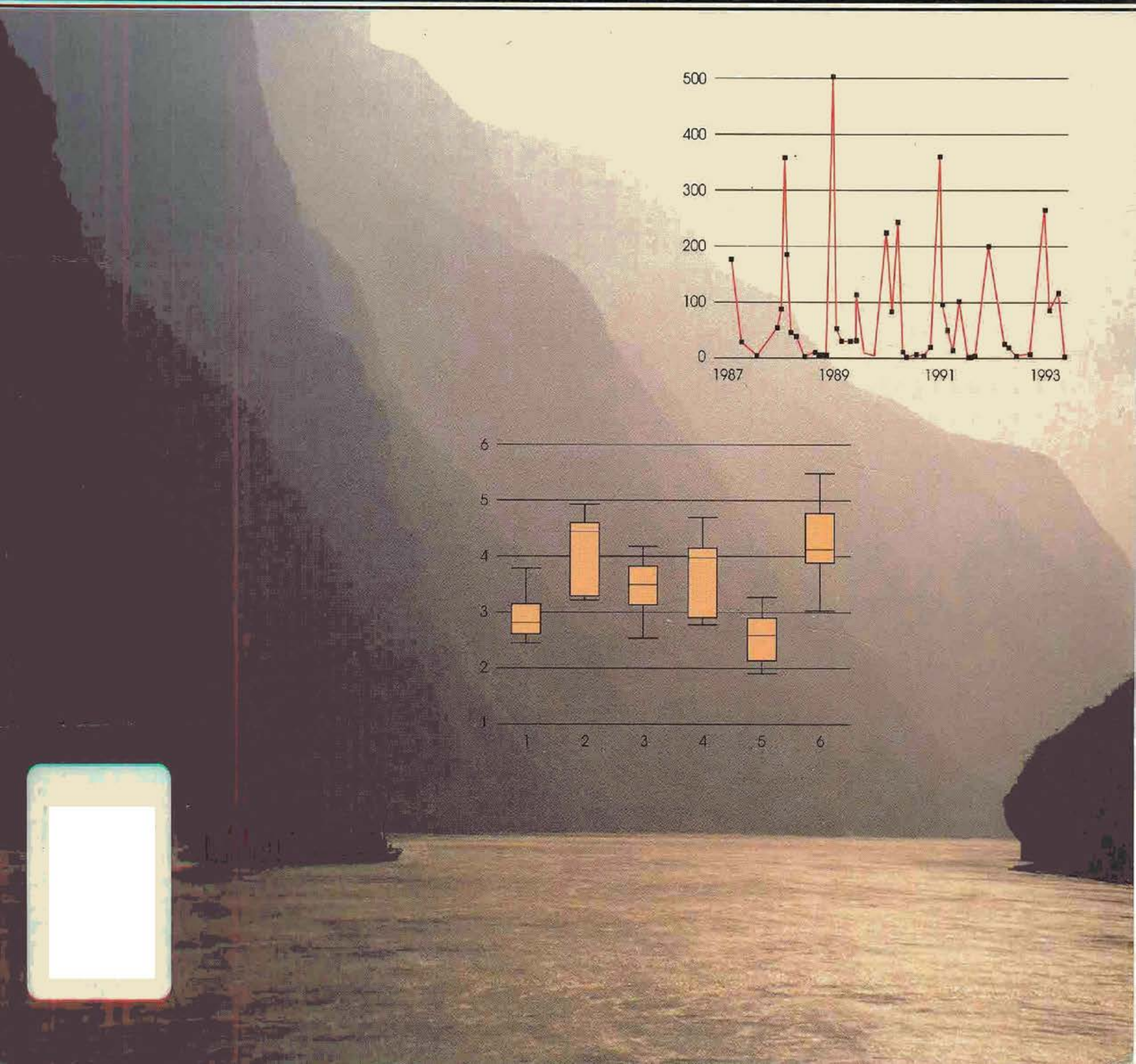
GLOBAL ENVIRONMENT MONITORING SYSTEM (GEMS)

WATER QUALITY OF WORLD RIVER BASINS



United Nations Environment Programme
Water Quality of World River Basins
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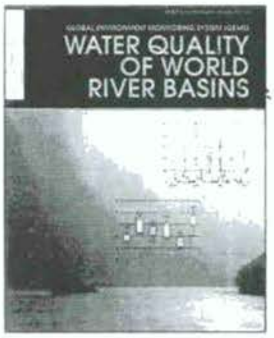

Cover: The Three Gorges region of the Chang Jiang river (Yangtze River). The area is characterized by steep relief and high suspended sediment concentrations. (photo: E. D. Ongley)

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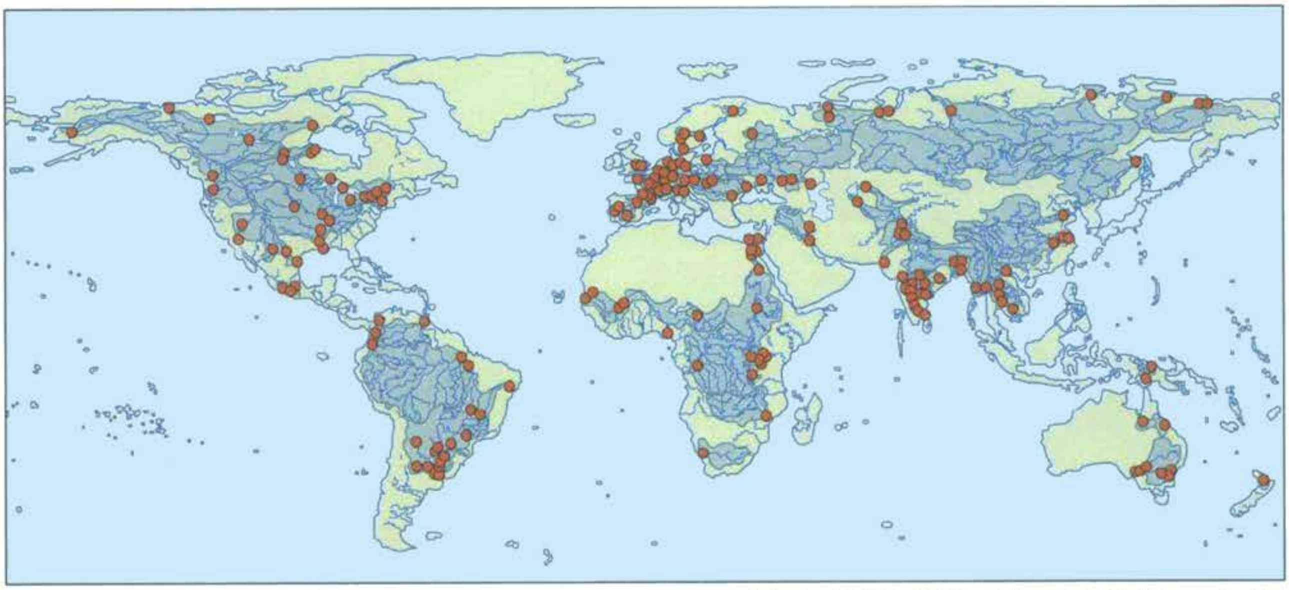

Subset of GEMS/Water stations used in this production

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Foreword

The understanding of the dynamic nature of our global fresh water resource is a challenge that the United Nations Environment Programme (UNEP) and the World Health Organization (WHO), in cooperation with UNESCO and WMO, address through the water quality component of the Global Environment Monitoring System (GEMS/WATER). The dynamic nature of these resources reflects the continuous interplay between the natural processes of geochemistry, hydrology, sedimentology and those activities associated with the human occupation of river basins.

The *Water Quality of World River Basins* selectively summarizes data contributed by countries participating in the GEMS/WATER Programme over the period 1976–90. The book also includes information gathered from many other sources. It summarizes the results of analysis and interpretation for 82 major river basins around the world. Some of these river basins are located in highly populated and industrialized areas where human impacts can be clearly seen. Other watersheds represent more pristine areas that are currently not under extensive human stress.

This publication contributes to the scientific investigation of global water resources. As global population increases and our demands on fresh water supplies grow, economic and development activities continue to increase the stress on natural ecosystems. Using examples drawn from the GEMS/WATER data bank, this volume demonstrates how natural processes interact with anthropogenic factors to create the observed water quality conditions.

It is said that knowledge empowers the individual. One of the essential purposes of the UNEP/GEMS Environment Library series is to disseminate knowledge of environmental conditions to people around the world who are directly or indirectly affected by changes occurring in this global resource. It is my hope that this publication will contribute to our knowledge of the trends and conditions of water resources in diverse regions of our world.

Elizabeth Dowdeswell
Executive Director
United Nations Environment Programme

Introduction

The GEMS/WATER Programme

The Global Environment Monitoring System (GEMS) grew out of the 1972 Stockholm Conference on the Environment. At that world conference, governments requested the establishment of a global monitoring programme that could determine the status and trend of key environmental issues. The GEMS/WATER Programme was initiated in 1976 by UNEP and the World Health Organization, with the assistance of UNESCO and WMO. The Programme had the twin objectives of improving water quality monitoring and assessment capabilities in participating countries, and determining the status and trends of regional and global water quality.

In Phase 1 of GEMS/WATER, 1976–90, the global network was established with the Global Data Centre located at the Canada Centre for Inland Waters, Canada. This publication summarizes data collected during Phase 1 of the Programme and marks the completion of the first phase of GEMS/WATER.

In Phase 2, the GEMS/WATER Programme has realigned its data network in order to focus on new global priorities such as land-based sources of pollution, toxic chemicals and the need for improved communication and decision skills for water quality management. The GEMS/WATER Programme works with other United Nations agencies and with donor countries to build new capacity in selected national agencies by offering programmes of analytical quality assurance, information systems and software, and more effective ways to carry out monitoring and assessment.

The GEMS/WATER Programme has published numerous books and reports on water quality issues at a global scale (ref. 24), water quality monitoring (ref. 25), and an Operational Guide for agencies participating in the programme (ref. 26).

About this publication

As with any global summary, data quantity and quality are variable, especially as the GEMS/WATER Programme relies on national water quality agencies to submit data to the GEMS/WATER Global Data Centre. Data submitted to the Global Data Centre are reviewed both manually and by automated data quality standards. Although data on major ions, nutrients and microbiological information are relatively complete, the reader will note that there is little information on toxic chemicals. This reflects the cost and difficulty of collecting and analysing these contaminants, especially in developing countries. To fill out the global picture, information is also drawn from other scientific sources.

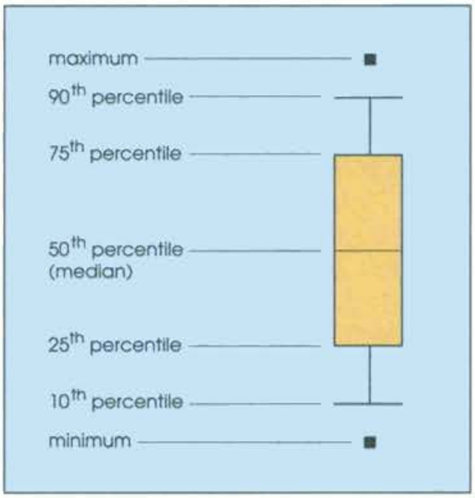
The data are presented by watershed (drainage basin). The 82 watersheds represent major world rivers, or smaller rivers that have regional significance. Water quality data are strongly site-dependent, and results must therefore be carefully assessed, especially when a watershed is characterized from a limited number of sampling points in time or space.

This publication also attempts to provide a basis for the scientific understanding of observed water quality conditions. The text represents, therefore, a compromise between scientific rigour and extreme simplification. The publication is organized around major themes that have significance for managing the quality of the Earth's surface waters. However, for a publication of restricted length, it is not possible to provide a complete regional and global summary of all water quality conditions. We have therefore chosen to provide selective overviews which take into account all the GEMS/WATER parameters, but use illustrations drawn from various parts of the world. Complete data for all 82 watersheds are provided in Tables at the end of the publication.

Throughout the analysis and production of this publication, the information processing system RAISON was intensively used. This system, developed by Environment Canada and used widely within the GEMS/WATER Programme, is a versatile and user-friendly computer software for integrating, analysing and displaying environmental and socio-economic information in a geographical context.

About statistical diagrams

Statistical plots for various parameters in this publication are given as box plots. These represent the 10th, 25th, 50th, 75th and 90th percentiles of the parameter distribution. They are generally presented for each of the continents and compared to the global distribution. The data used in these comparisons are derived from the GEMS database. These figures should be used with caution since the existing database is fairly sparse in regions such as Africa and parts of South America.



Acknowledgement

The 60 countries, large and small, that contribute data to the GEMS/WATER programme can take much of the credit for this volume. The provision of data by Russia filled a large geographical gap that had existed in the GEMS/WATER programme and we thank Dr V. Tsirkunov for his participation. WHO regional offices have been important focal points for country participation. The authors wish to acknowledge specifically Kelly Hodgson and Janice Jones for their major contribution in the development of this publication. We also acknowledge the personal involvement of Dr V. Vandeweerd (UNEP) and Dr R. Helmer (WHO) in the enterprise. The Canadian Government, through Environment Canada, and Foreign Affairs and International Trade Canada, provided significant financial support for this project through their support of the GEMS programme.

Water quality

Water quality is closely linked to water use and to the state of economic development.

In industrialized countries, faecal contamination of surface water caused serious health problems (typhoid and cholera) in large cities in the mid-1800s. At the turn of the century, cities in Europe and North America began building sewer networks to route domestic wastes further downstream of water intakes. Development of sewage networks and waste treatment facilities in urban areas has expanded enormously in the past two decades. However, the rapid growth of urban population, especially in Latin America and Asia, has outpaced the ability of governments to expand sewage and water infrastructure. While water-borne diseases have been virtually eliminated in the developed world, outbreaks of cholera and other gastro-enteric diseases still occur with alarming frequency in developing countries.

Since World War II and the dawn of the 'chemical age', water quality has been heavily affected worldwide by industrial and agricultural chemicals. Eutrophication of surface waters from human and agricultural wastes, and nitrification of groundwater from agricultural practices, has affected large parts of the world. Acidification of surface waters by air pollution is a recent phenomenon and threatens aquatic life in many areas. In developed countries, these general types of pollution have occurred sequentially with the result that most developed countries have successfully dealt with major surface water pollution. In contrast, newly industrialized countries such as China, India, Thailand, Brazil and Mexico, are now facing all these issues simultaneously.

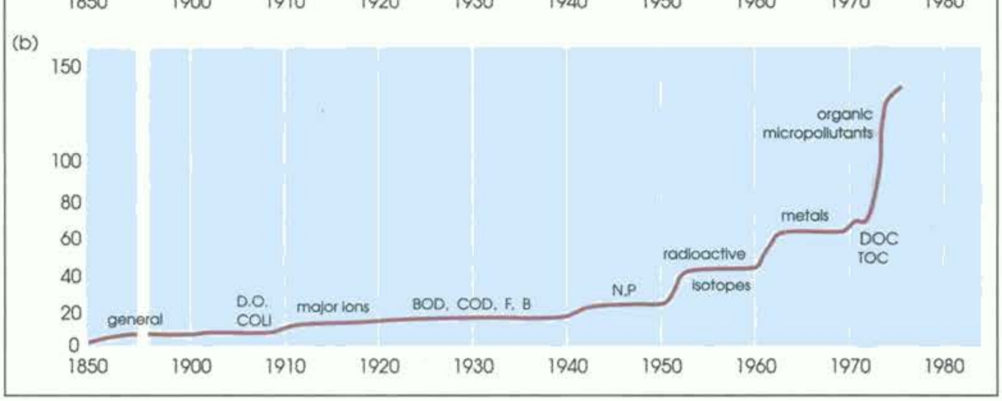


Figure 1

a) Conceptual evolution of major water quality issues.

b) Water quality variables considered in surveys.

(ref. 4, reproduced by permission).

Natural factors regulating water quality

If there was no human influence, water quality would be determined by the weathering of bedrock minerals, by atmospheric processes of evapotranspiration and the deposition of dust and salt by wind, by the natural leaching of organic matter and nutrients from soils, and by hydrological factors that lead to runoff.

Surface runoff is extremely variable. It is influenced by latitude, local differences in elevation (orography) and location on continents. In equatorial and monsoon regions, runoff exceeds 2000 mm/year or 63 litres km^{-2} s^{-1}. In regions where runoff is less than 25 mm/year, rivers are not perennial unless fed by wetter basins further upstream.

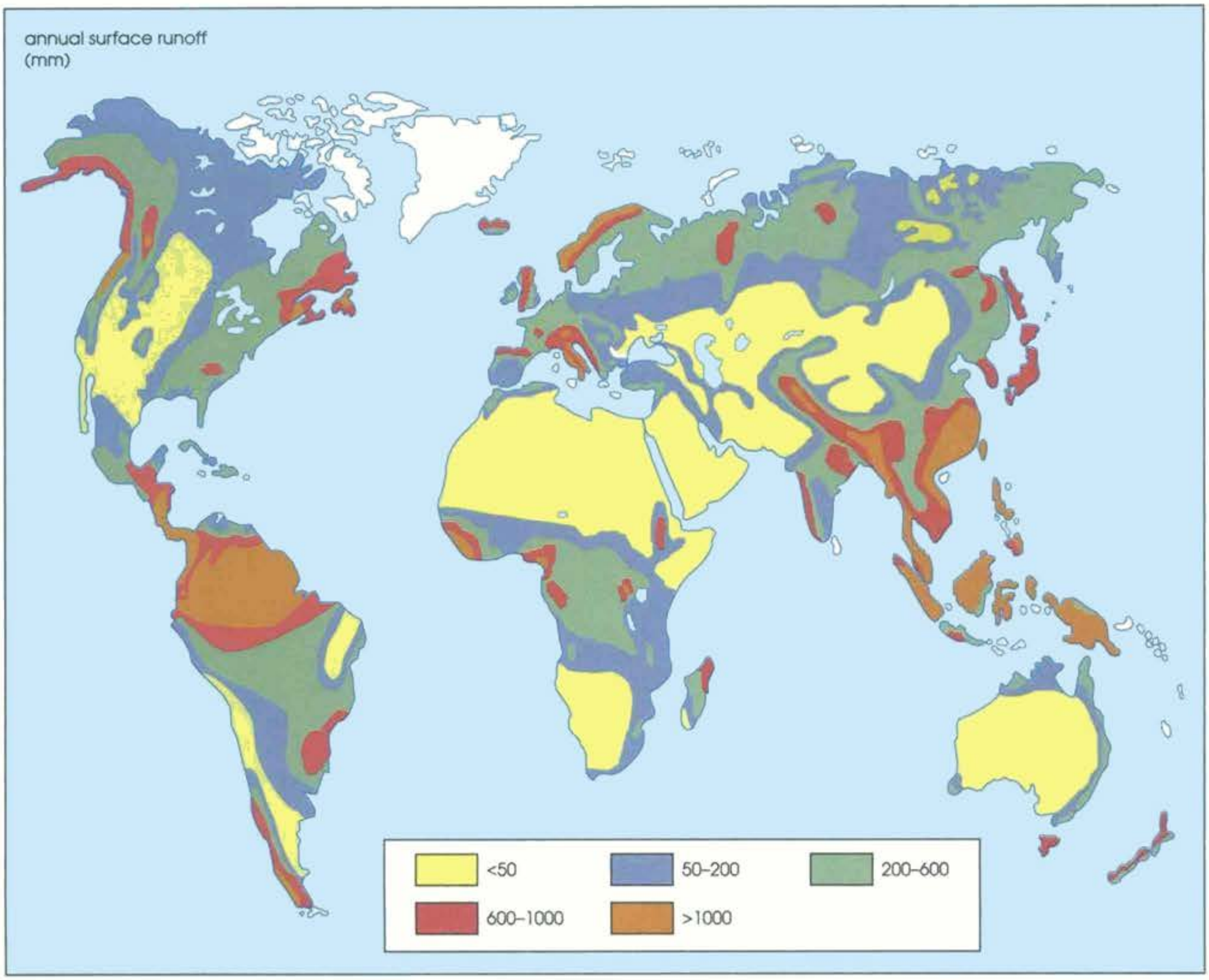


Figure 2 Global distribution of annual surface runoff (ref. 1, reproduced by permission).

Hydrology

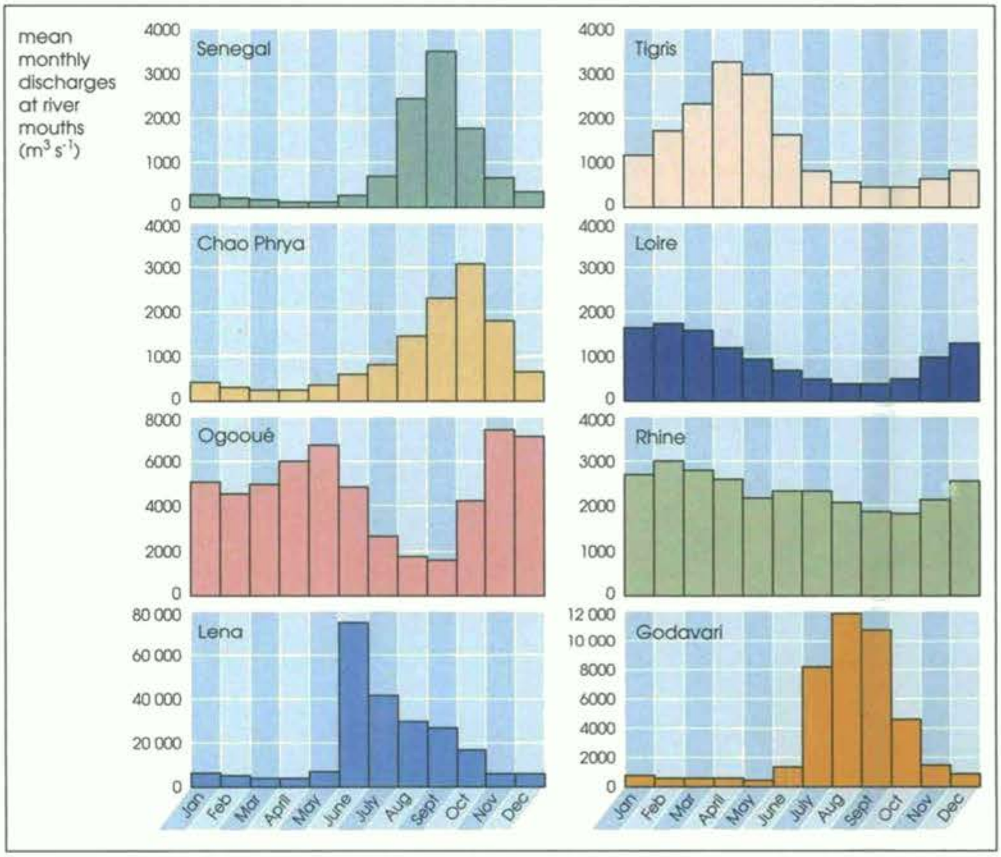


Figure 3 Selected hydrographs for average monthly discharges at river mouths (ref. 2).

Discharge is the first factor that controls water chemistry, mainly through dilution. Discharge is also closely related to the transport of suspended sediment in rivers. Without continuous discharge measurement, fluxes (transport) of sediment and chemicals in rivers cannot be calculated. A plot of discharge through time is called a hydrograph (Figure 3). The shape of the hydrograph is linked to river size, river regime and the effects of lakes or groundwater.

Long-term monthly discharges characterize the regime of a river. Some examples are given in Figure 3:

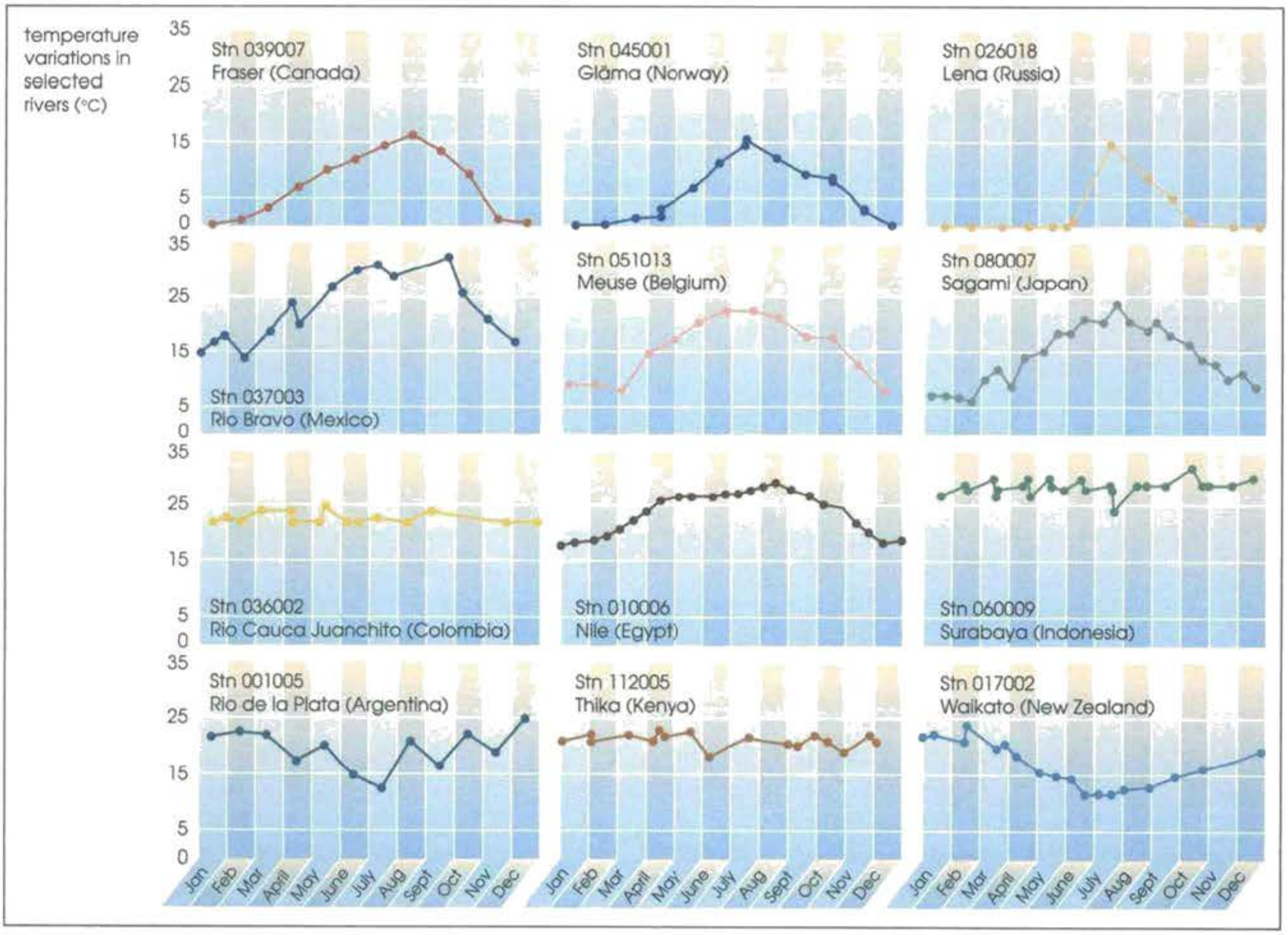
- tropical with maximum linked to rainfall pattern (Senegal);
- mountain snow melt and rainfall (Tigris);
- late monsoon rainfall (Chao Phrya);
- oceanic type linked to evapotranspiration pattern (Loire);
- equatorial with two maxima linked to rainfall pattern (Ogooué);
- complex regime from glacier melt to oceanic type (Rhine);
- lowland snow melt (Lena); and
- early monsoon type (Godavari).

Thermal characteristics of river waters

The rate of chemical and biological processes in surface waters, especially oxygen level, photosynthesis and algal production, are strongly influenced by temperature. Temperature is also an important variable for aquatic biota, particularly for fish. The thermal characteristics of lakes and reservoirs are a major factor in planning for effluent management and for withdrawal of water for industrial cooling purposes.

Temperature variation in surface water depends on local climate and on upstream influences such as snow and glacier melting, and occurrence of lakes. Siberian rivers, such as the Lena at its mouth, are frozen during eight months of the year while at the equator water temperature is nearly constant, 30 °C at sea level (Surabaya) and 23 °C at higher altitude (Thika). Seasonal variations are maximum at mid-latitudes where they can exceed 25 °C. Thermal pollution, which occurs for example in the Meuse, rarely exceeds a few degrees and is usually masked by larger seasonal trends.

Figure 4 Temperature variations in selected rivers depicting latitudinal effects for selected years.



Suspended solids and water quality

Total Suspended Solids (TSS) is comprised of organic and mineral particles that are transported in the water column. TSS is closely linked to land erosion and to erosion of river channels. TSS can be extremely variable, ranging from less than 5 mg per litre to extremes of 30 000 mg per litre in some rivers. TSS is not only an important measure of erosion in river basins, it is also closely linked to the transport through river systems of nutrients (especially phosphorus), metals and a wide range of industrial and agricultural chemicals.

In most rivers TSS is primarily composed of small mineral particles. TSS is often referred to as 'turbidity' and is frequently poorly measured. Higher TSS (more than 1000 mg per litre) may greatly affect water use by limiting light penetration and can limit reservoir life through sedimentation of suspended matter. TSS-levels and fluctuations influence aquatic life, from phytoplankton to fish. TSS, especially when the individual particles are small (less than 63 µm), carry many substances that are harmful or toxic. As a result, suspended particles are often the primary carrier of these pollutants to lakes and to coastal zones of oceans where they settle. In rivers, lakes and coastal zones these fine particles are a food source for filter feeders which are part of the food chain, leading to biomagnification of chemical pollutants in fish and, ultimately, in man. In deep lakes, however, deposition of fine particles effectively removes pollutants from the overlying water by burying them in the bottom sediments of the lake (see Figures 45 and 46). In river basins where erosion is a serious problem suspended solids can blanket the river bed, thereby destroying fish habitat.

Sediment yield, expressed as tonnes km^{-2} year^{-1}, is calculated by dividing the total annual TSS load (tonnes) by the surface area of the watershed (km^2). Sediment yield is a key indicator of land erosion. Estimates of the average global annual sediment load to the world oceans varies from 15 to 30 billion tonnes (ref. 5, 6 and 7).

The large sediment loads to oceans in south-east Asia are two-thirds of the world's total sediment transport to oceans. This arises from the combination of active tectonics, heavy rainfall, substantial local relief with steep slopes, and erodible soils including the loess belt of northern China. The Huang He (Yellow) produces 1080 million tonnes of sediment annually; 480 for the Chang Jiang (Yangtze), 460 for the Ganges, and 710 for the Brahmaputra. Reservoir construction (Indus, and a future dam on the Chang Jiang) may affect these numbers in the future. In comparison, low

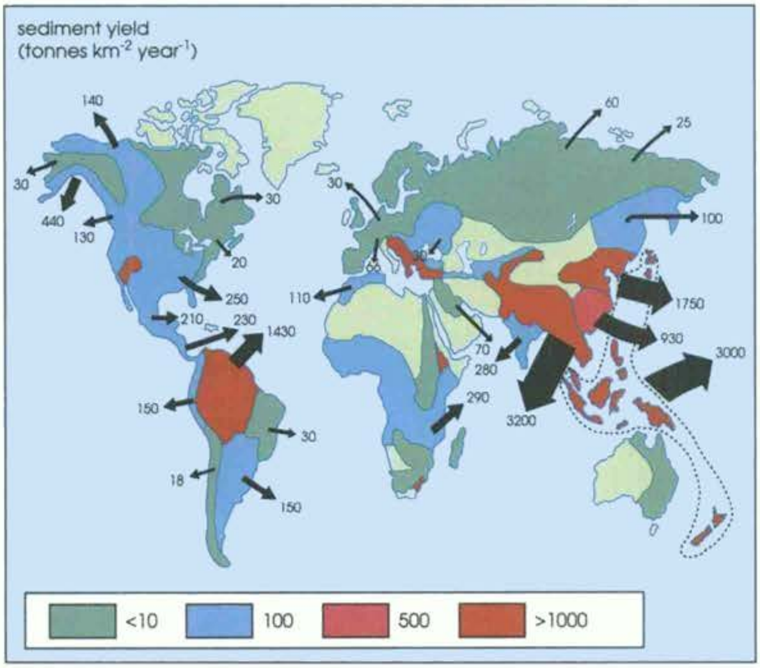
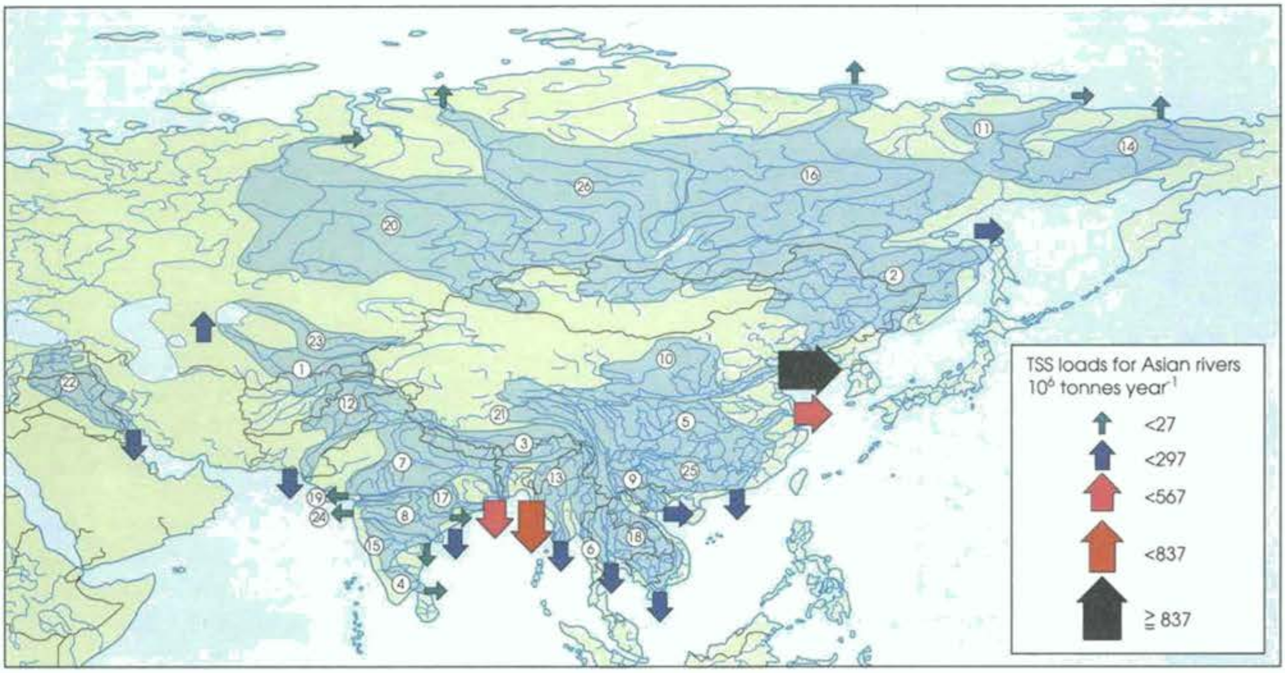


Figure 5 Global pattern of sediment yield, with river outputs of sediment to the oceans. Figures are in million tonnes (ref. 6, reproduced by permission).



relief, low precipitation and permafrost greatly reduce turbidity and sediment loads in Siberian rivers (about 15 million tonnes for each of the Ob, Yenissei and Lena, ref. 7).

Time series of instantaneous TSS loads (kg s^{-1}) provide useful information about the physical behaviour of rivers. Because total suspended solids concentration is partly a function of discharge, TSS load increases as discharge increases. In many rivers, the amount of sediment (solids) in transport (the load) can vary over three or more orders of magnitude during the year.

Typical of most rivers, TSS peak loads in the Rhine River (Figure 8) occur only during short periods (days), and often are not identified when rivers are sampled on a bi-monthly or monthly basis. This can lead to major errors in calculating sediment transport.

Figure 6 Total Suspended Solids (TSS) loads for Asian rivers. Basin numbers are identified in Table 3 on page 34 (data from ref. 7).

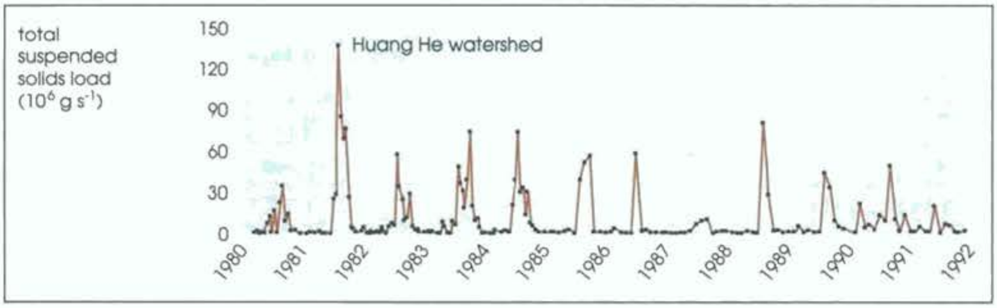


Figure 7 TSS instantaneous load for Huang He station 005002, China.

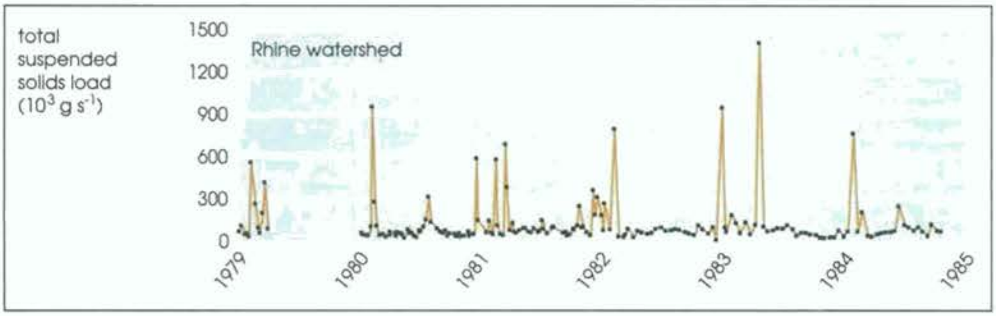


Figure 8 TSS instantaneous load for Rhine River station 046001 at the German frontier.

Oxygen balance in rivers

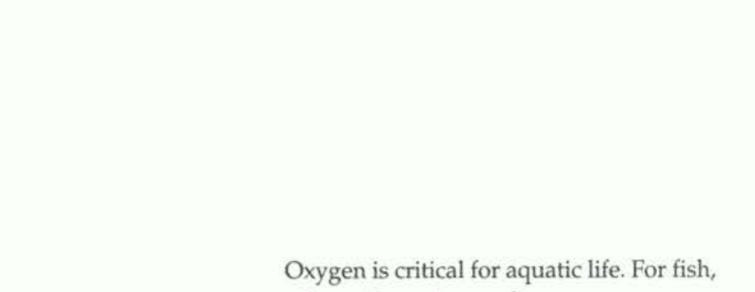
Oxygen is critical for aquatic life. For fish, salmonid species need oxygen concentrations greater than 5 mg per litre ; cyprinids (carp family) need more than 2 mg per litre. Oxygen is a key factor in the biogeochemical processes that modify and reduce pollutant loads in rivers.

Dissolved oxygen in natural running waters should be close to 100 percent saturation, that is, between 9 and 11 mg per litre, depending on temperature. Oxygen depletion is usually caused by bacterial degradation of organic matter. The potential for oxygen consumption is measured as BOD_5 (Biochemical Oxygen Demand over a five-day period) and/or by the oxidization of chemical bonds (Chemical Oxygen Demand—COD). Oxygenation of water occurs naturally through turbulence of river waters and by vertical mixing in lakes.

Global BOD_5 levels measured at GEMS/WATER stations average 2 mg per litre which indicates a limited degree of organic pollution. Much higher observed values are usually associated with discharge of municipal wastewater, and wastes from agro-food and some types of industrial effluents. In contrast with most North American stations, South American stations have the lowest BOD levels. An urban water body from Djakarta City has a high degree of organic pollution and can be virtually devoid of oxygen. The relationship between BOD and COD for this canal is typical of the poor water quality found in rivers running through many fast-growing megacities in Latin America and Asia (Figure 10). The Espierre River that flows from France to Belgium (Figure 11) is actually an urban and industrial sewer.

The Xi Jiang (Pearl River) shows natural variability of BOD_5 ranging from 0.3 to 1.2 mg per litre for 12 years of records. Such low levels are rarely found in the GEMS/WATER database. The Xi Jiang also demonstrates how higher values of BOD_5 are associated with low flow of a river when effluents are least diluted.

Figure 9 Statistical distribution of BOD per continent.



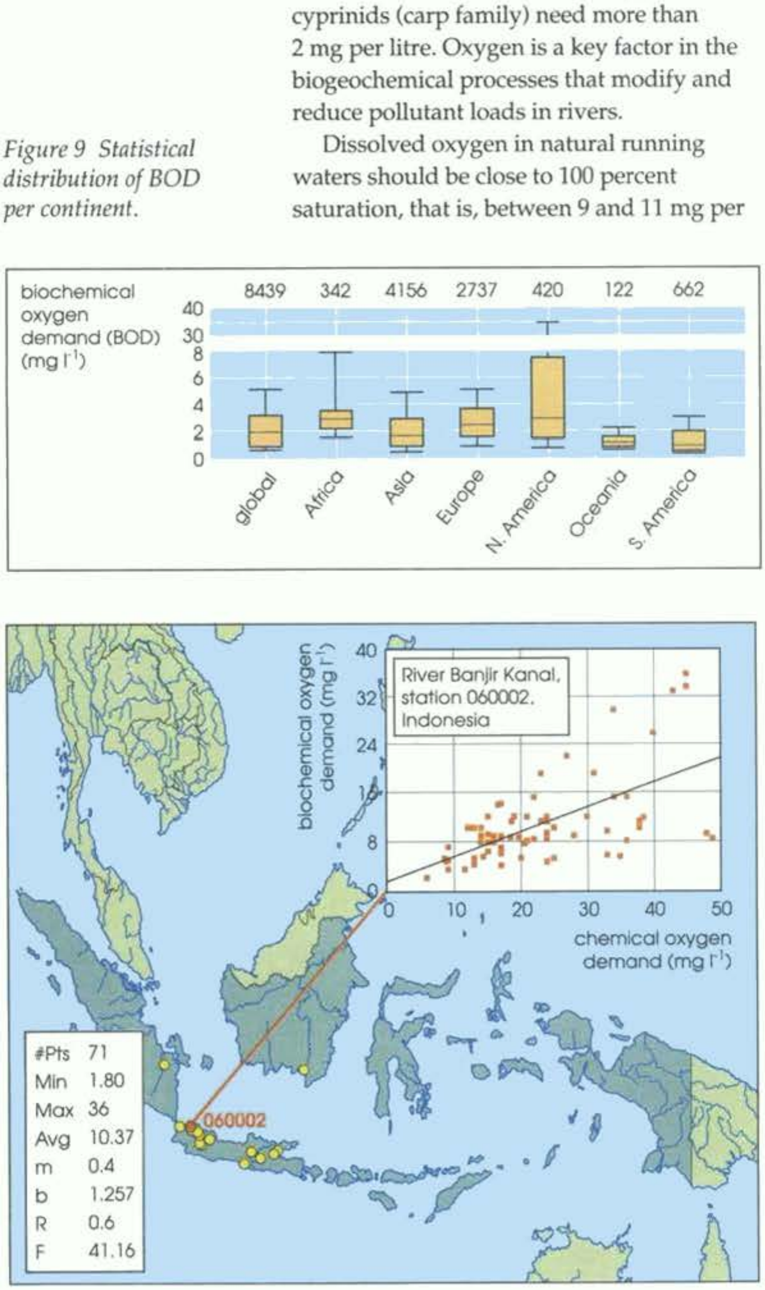


Figure 10 BOD vs COD regression in the Banjir Canal, Djakarta, Indonesia.

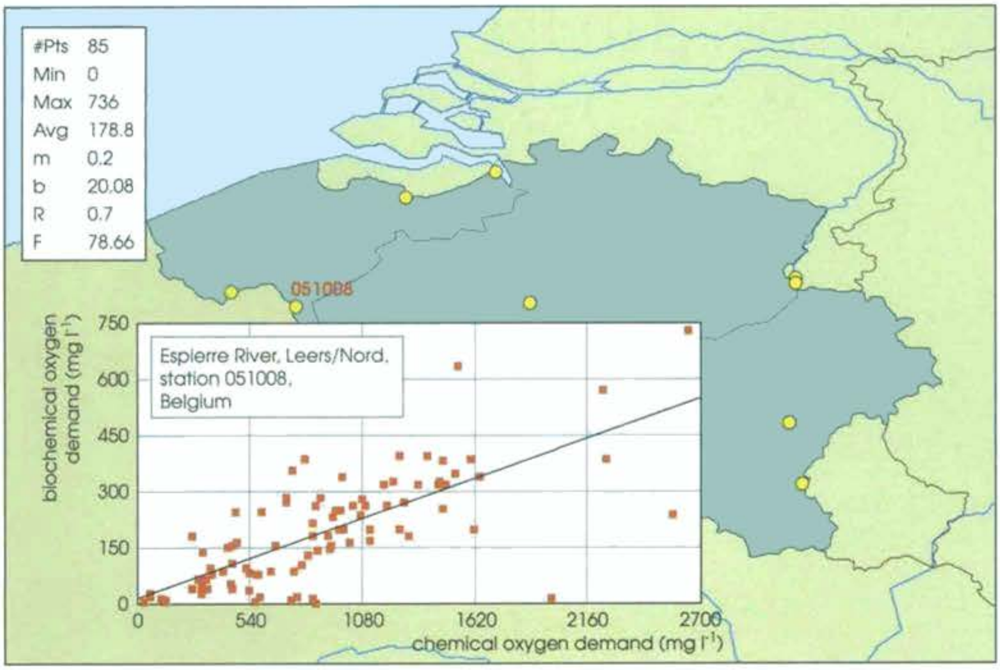


Figure 11 Relationship between BOD and COD in the Espierre River, Belgium.

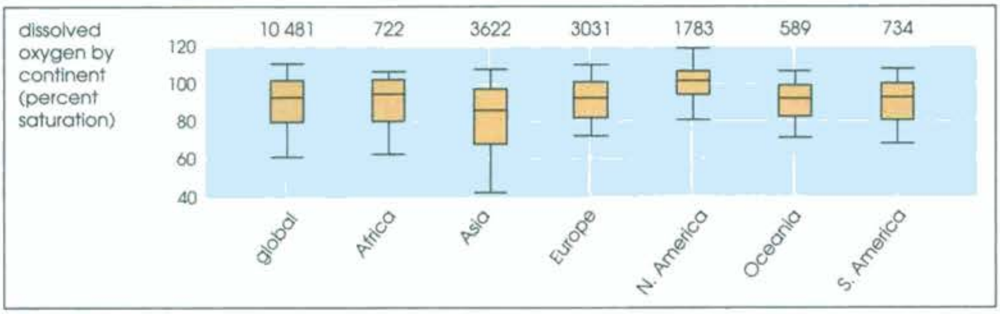


Figure 12 Statistical distribution of oxygen percent saturation by continent. Note that percent saturation of oxygen can exceed 100 percent due to temperature effects and biological activity.

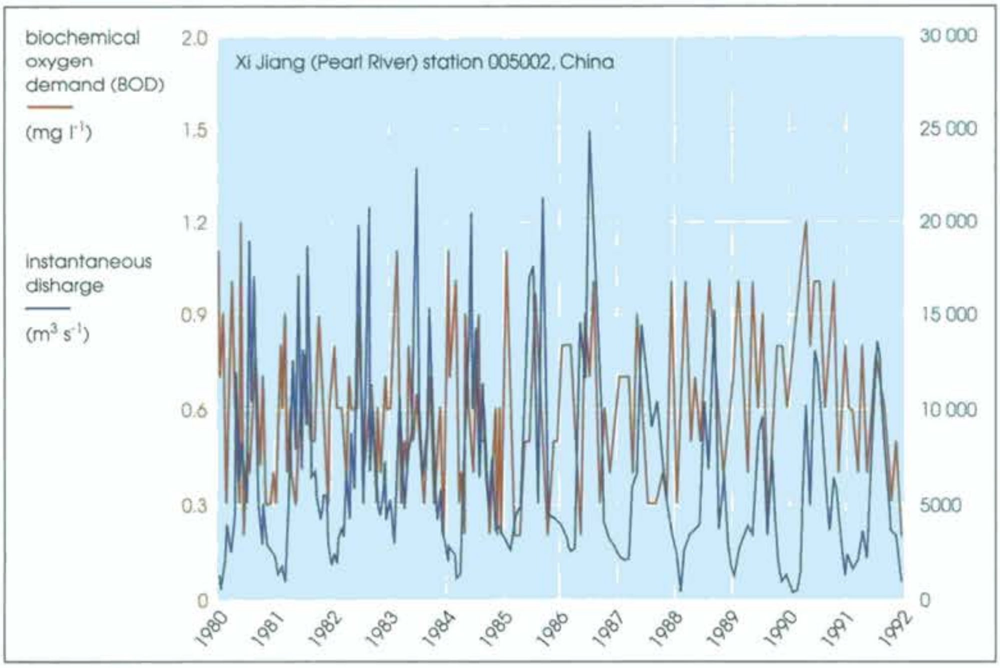


Figure 13 Time series for BOD_5 and discharge in the Xi Jiang, China.

Microbial pollution

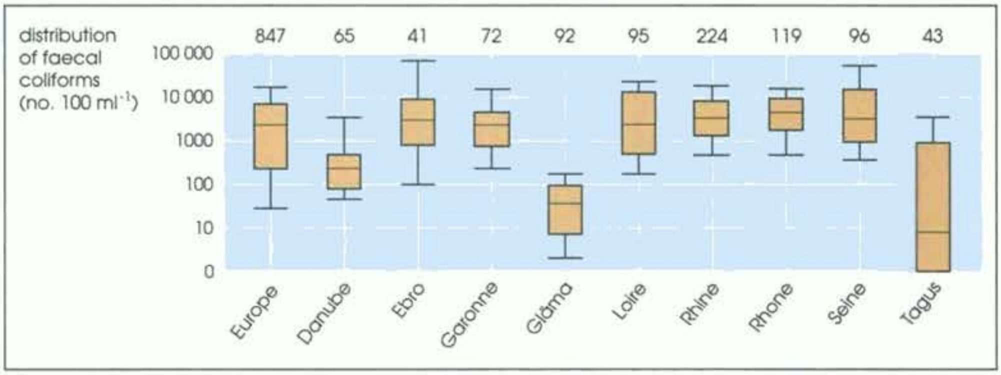


Figure 14 Statistical distribution of faecal coliforms for stations located on some European rivers.

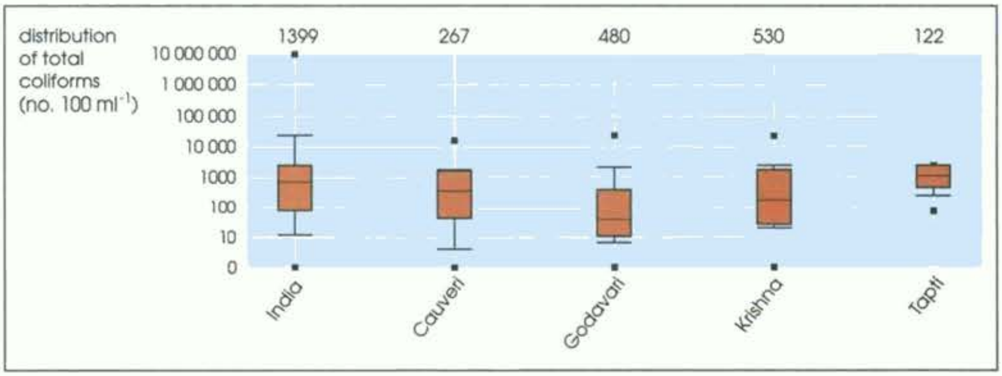


Figure 15 Statistical distribution of total coliforms reported for stations located on some Indian rivers. Solid dots are maximum and minimum recorded values.

Freshwater bodies polluted by faecal discharges from man, pets, farm animals and wild animals may transport a variety of pathogens such as bacteria (Shigella, Salmonella, Cholera Vibrio, Escherichia), viruses and protozoans. According to the WHO, waterborne diseases account for 5 million deaths annually, worldwide (ref. 30).

Detection of all potential waterborne pathogens is difficult; therefore most water quality surveys use various indicators of faecal contaminations such as total coliforms and faecal coliforms. Bacterial counts, expressed in number per 100 ml, may vary over several orders of magnitude at a given station. They are the most variable of water quality measurements.

In rivers that are relatively free of faecal discharges, or at stations located far downstream of sewer outfalls, total faecal counts are less than 100/100 ml as in the Gläma for example (Figure 14). Most of the GEMS stations in Europe reflect a marked contamination with counts between 1000 and 10 000/100 ml with occasional peaks exceeding 100 000/100 ml. In rivers that receive untreated sewage, coliform counts can well exceed 100 000 counts/100 ml. The lower values in India (Figure 15) relative to European rivers probably reflect methodological and reporting differences.

Salts and salinization of surface waters

Salts are composed of a combination of chemical ions such as sodium (Na$^+$), potassium (K$^+$), calcium (Ca^{++}), magnesium (Mg^{++}), chloride (Cl$^-$), sulphate (SO$_4^{--}$) and bicarbonate (HCO$_3^-$). Ions that are positively charged are called cations and those that are negatively charged are called anions. The cations (Ca^{++}, Mg^{++}, Na$^+$, K$^+$) and anions (Cl$^-$, SO$_4^{--}$, HCO$_3^-$) are collectively known as major ions. Concentrations of these major ions are basic descriptors of water quality on which many criteria for water use are based (such as drinking water, agriculture and industrial use).

Total Dissolved Solids (TDS) is a measure of the total amount of major ions (plus silica—SiO$_2$) in water. TDS are naturally highly variable in surface waters and there is no global reference value that can be used to assess a contamination level. In coastal areas, river chemistry can reflect marine salt deposited in rain water. Lake chemistry depends primarily on the hydrological balance of the lake. Lakes with outlets tend to reflect the chemistry of their tributaries, while lakes without outlets have waters that may be saline (TDS more than 3 g per litre to a maximum of 300 g per litre) due to evaporation (Dead Sea, Lake Assal in Djibouti, Kara Bogaz in Turkmenistan). Lake studies are presented on page 28.

Calcium, magnesium and potassium

Calcium, the most common cation found in surface waters, is mainly a function of geology especially when carbonate or gypsum deposits are present.

Concentrations of magnesium are not strongly influenced by anthropogenic activities and therefore magnesium is not used as an indicator of pollution stress.

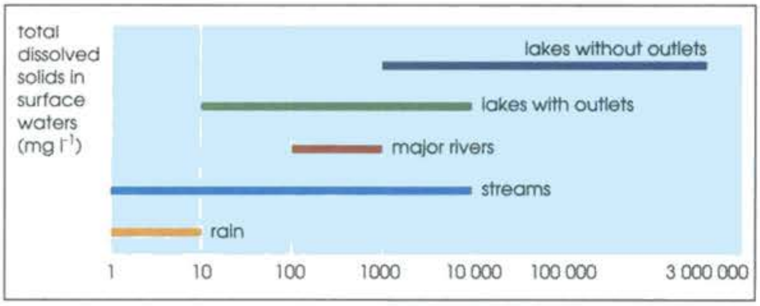
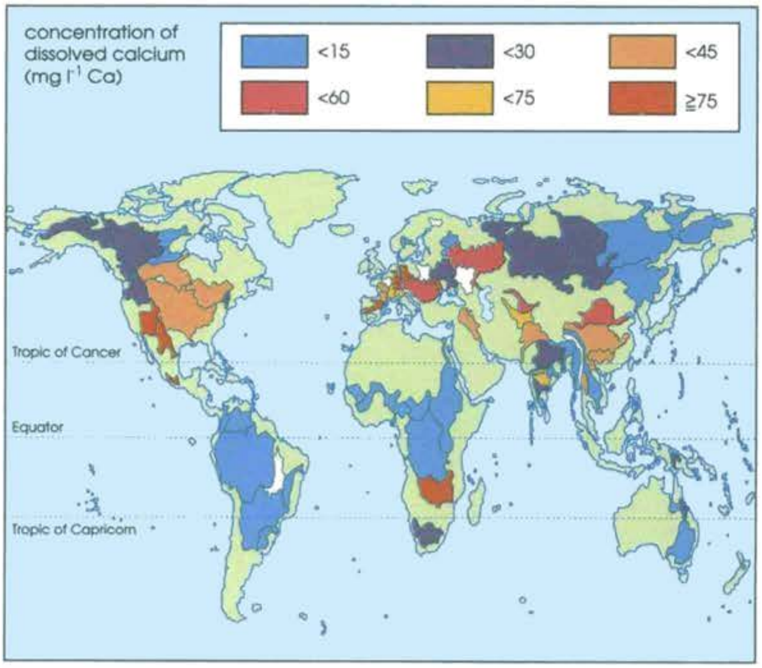


Figure 16 Range of TDS in surface waters (note log scale).

In comparison with other continents (Figure 18), European rivers have the highest concentration levels of Ca^{++}. These continental differences are not caused by anthropogenic impacts but by geological influences. At the global scale, natural Ca^{++} levels range from 0.06 to 210 mg per litre in streams (<100 km^2) and from 2 to 50 mg per litre in major rivers (>100 000 km^2); see ref. 4.

Figure 17 Global variation of average calcium concentration at major river mouths.



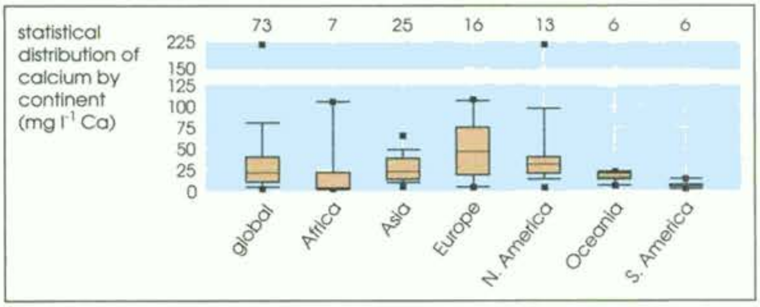


Figure 18 Statistical distribution of calcium by continent based upon averages at major river mouths.

Potassium-bearing minerals, mostly feldspar and mica, are abundant but poorly soluble. Natural potassium concentrations in rivers are very low (less than 5 mg per litre). Even though potassium is affected by fertilizer use, it never reaches levels of concern for water quality. The highest K^+ concentrations in selected European watersheds are found downstream from major mining districts (potash and salt mines) on the Rhine, Weser and Elbe rivers, where concentrations may exceed the 12 mg per litre WHO guideline for drinking water.

Sodium and chloride

In most waters sodium and chloride are tightly linked. They both originate from natural weathering of rock and from atmospheric transport of oceanic inputs and from a wide variety of anthropogenic sources. The WHO drinking water guideline for Cl^- is 200 mg per litre.

The anthropogenic sources of sodium and chloride are so pervasive that concentrations of sodium and chloride have risen by a factor of 10 to 20 in many rivers.

Since 1889 there has been a five-fold increase in Cl^- concentrations at the water intake (Ivry) for the City of Paris (Figure 20).

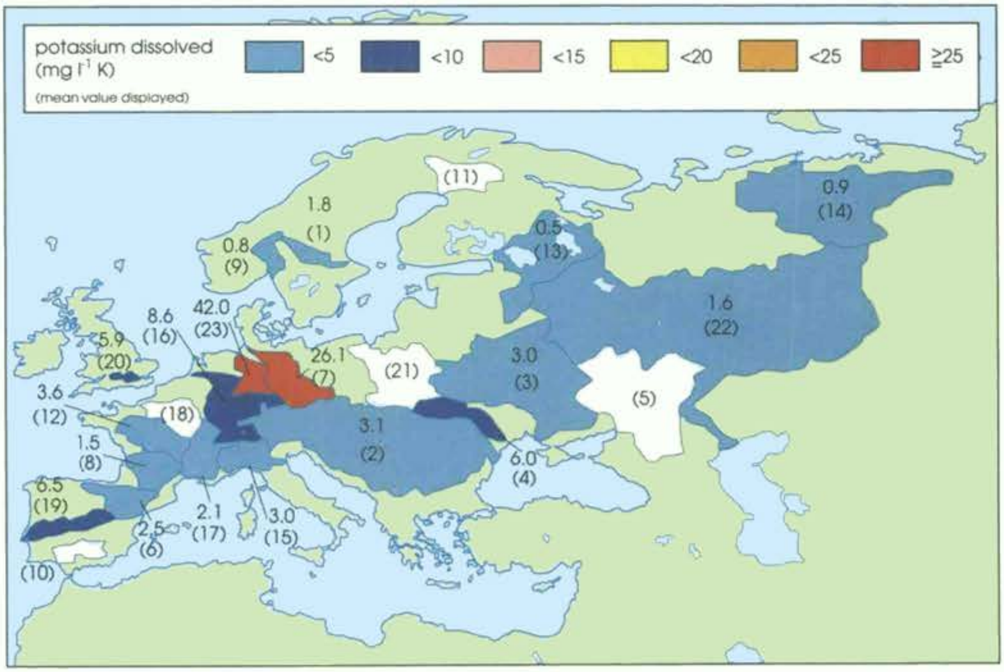
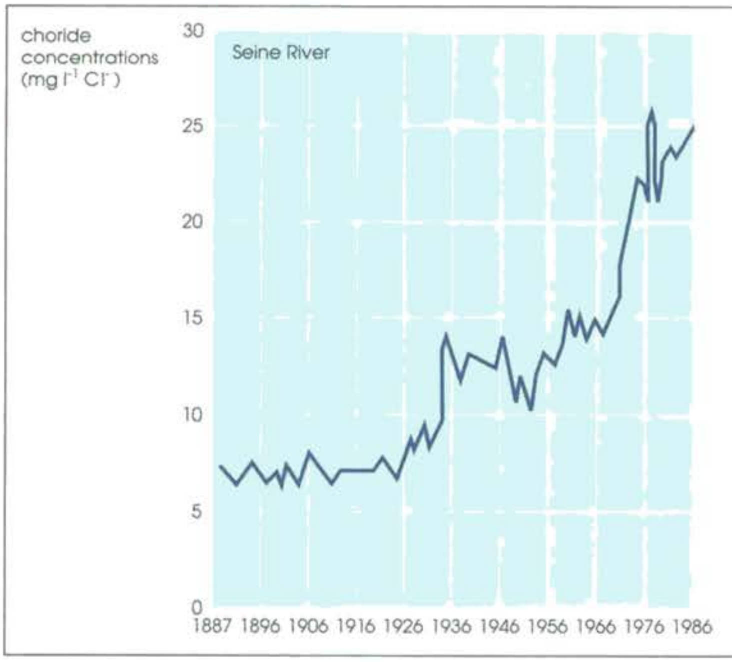
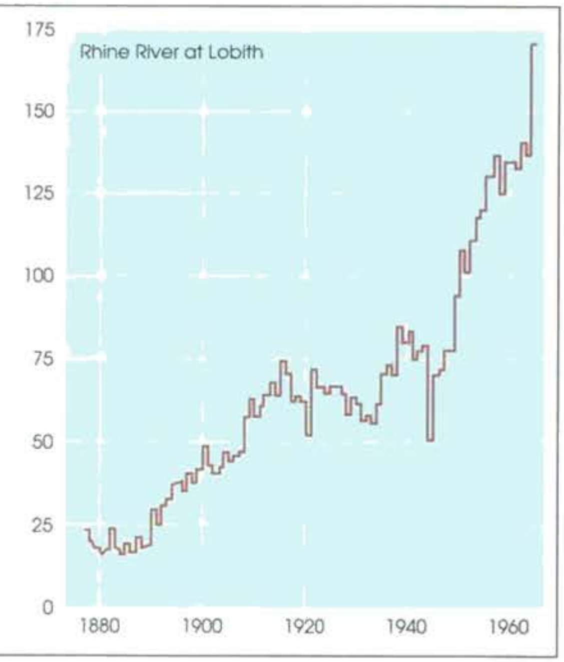


Figure 19 Average potassium concentration at major river mouths in Europe. Numbers in brackets identify watershed (see Table 5).





The background concentration is estimated to be about 5 mg per litre and originates from marine aerosols. The increases in Cl⁻ concentrations result from anthropogenic activities occurring upstream from this station. Present Cl⁻ concentrations are well below the WHO standard for drinking water (200 mg per litre).

The Rhine River suffers from two major salt sources—the Alsace potash mines and the Lorraine salt mines, both located in France. The brine from these sites is discharged to the Rhine downstream of Basel and to the Mosel River, respectively. The Alsace source (15 000 tonnes NaCl/day) represents 30 percent of the Cl⁻ flux measured at Lobith at the German/Netherlands border. Other contributions are mostly urban and industrial from the Ruhr area. Since the opening of potash

Figure 20 (top left) Long-term trend in chloride for the Seine River (ref. 13, reproduced by permission).

Figure 21 (top right) Long-term trend in chloride at the German/Netherlands border, Lobith (ref. 14, reproduced by permission).

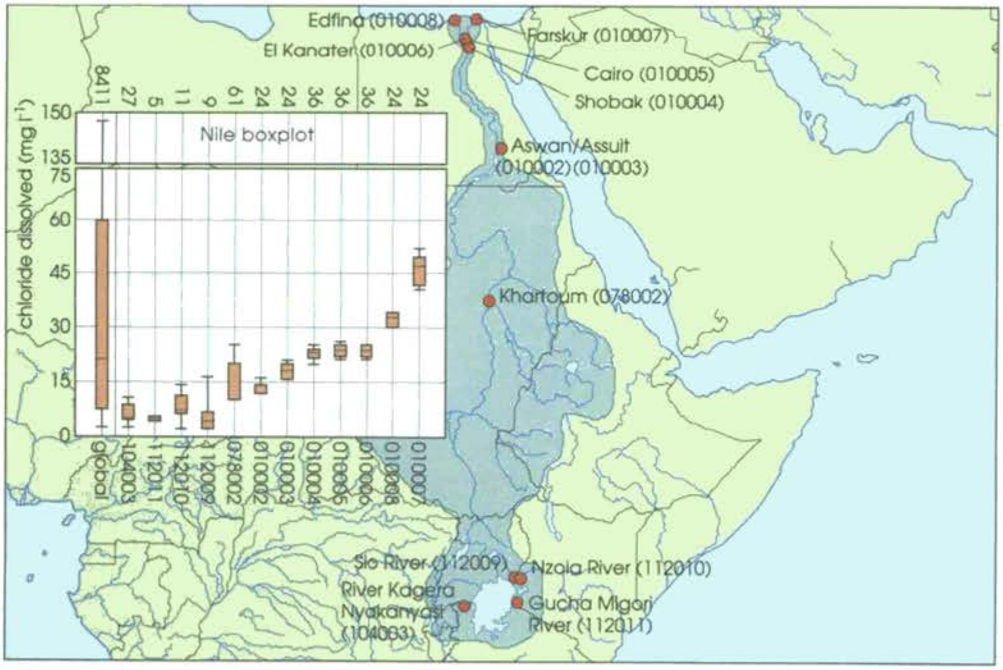


Figure 22 Longitudinal profile of chloride in the Nile River basin.

mines, 100 years ago, Cl⁻ levels and fluxes have increased by a factor of 15 to 20. The WHO standard for drinking water has been exceeded, as well as the guideline for greenhouse watering, a very important activity in the Netherlands.

In the Nile basin, chloride concentrations are lowest in Lake Victoria tributaries. Most of the Cl⁻ originates from atmospheric fallout and hydrothermal activity. Cl⁻ concentration increases at Khartoum from evaporation in the Sudd swamps of southern Sudan. As the Nile proceeds northwards across the desert, evaporation continues to dominate, raising the Cl⁻ concentration to 15 mg per litre. Nile water remains in Lake Nasser for approximately two years; as the flow continues to the delta region, municipal and industrial wastes, along with irrigation practices, raise the concentration significantly. The estimated five-fold decrease in water discharge to the Mediterranean Sea (ref. 16) since construction of the High Aswan Dam has led to a lack of dilution capacity that was formerly present in the Nile.

Chloride in the Krishna River, India, originates from atmospheric fallout and domestic sources, concentrated by evapotranspiration. In upstream stations to the west, Cl⁻ levels are relatively high, most probably resulting from marine aerosols driven inland by westerly winds.

In arid and semi-arid areas of the world (see Figure 24) evapotranspiration leads to an increase in the salt content (salinization) of surface waters and to an increase in sodium and calcium concentrations. The ratio of sodium to calcium is a key descriptor in water for irrigation.

Water quality is often affected by

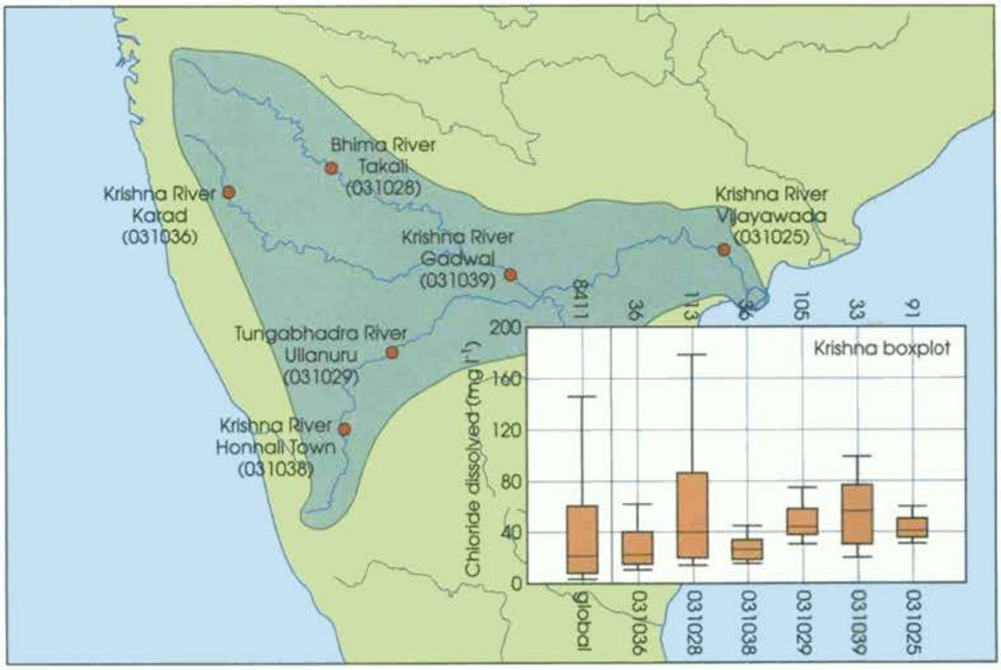


Figure 23 Longitudinal profile of chloride in the Krishna River basin.

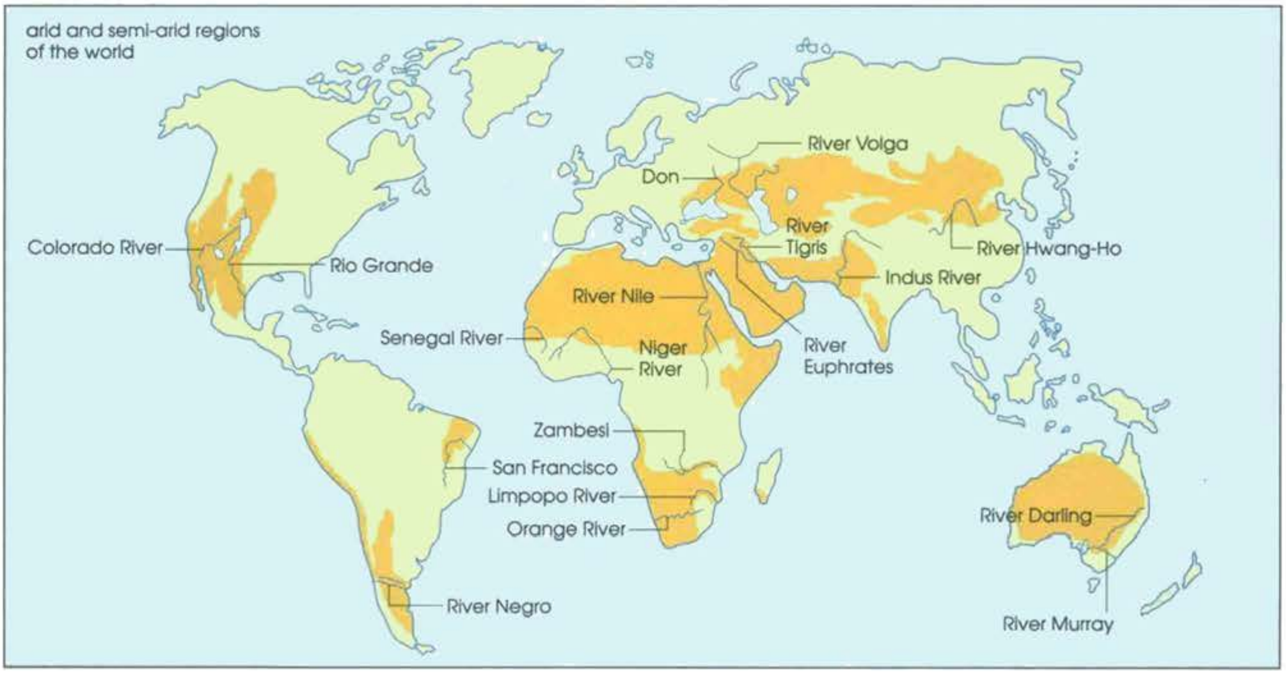


Figure 24 (above) Arid and semi-arid regions of the world (ref. 3, reproduced by permission).

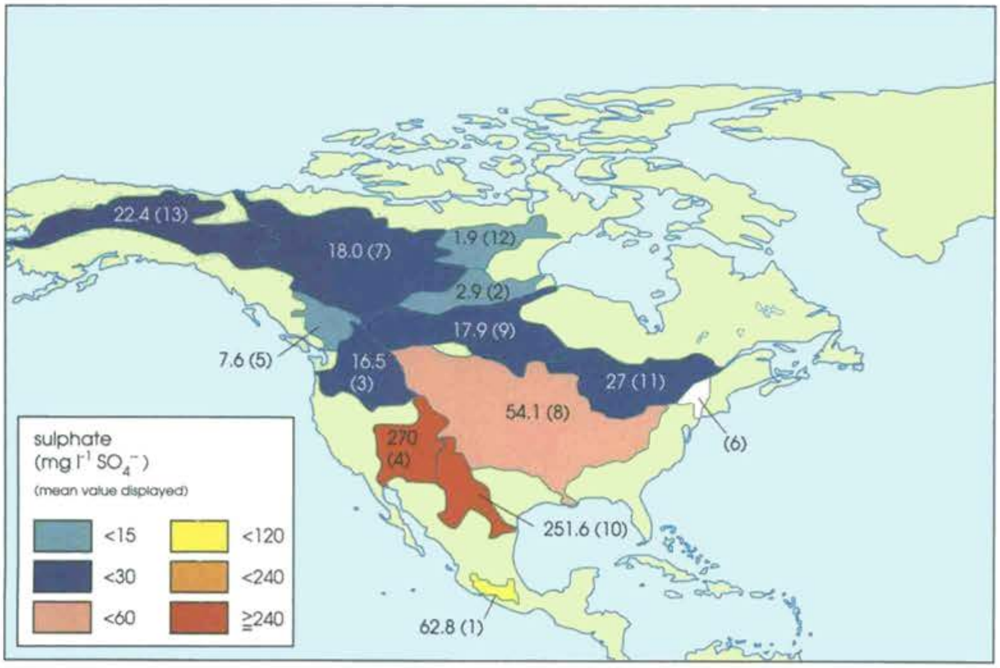


Figure 25 Average sulphate content at major river mouths in North and Central America. Numbers in brackets identify watershed (see Table 1).

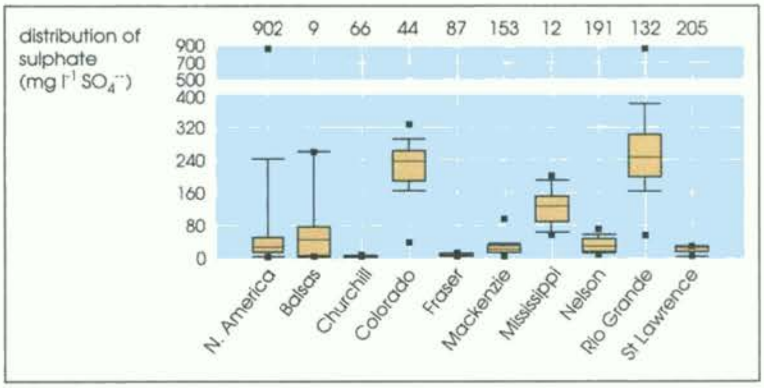


Figure 26 Distribution of sulphate in North and Central America at major river mouths.

salinization, particularly in surface waters, because of evaporation and the deposition of salts. Some rivers flow through arid regions when their source lies in wetter parts of upper basins (Colorado, Rio Grande, Orange, Nile, Indus, Murray). About 50 percent of arid land is located in 'endorheic' regions whence there is no flow to the oceans. In these regions, rivers flow into lakes such as the Caspian, Aral, Chad, Great Salt, Eyre and Titicaca, which have no outlets.

Dissolved salt content is regulated by the weathering of a few key minerals (halite and gypsum, carbonates and silicates, in decreasing order of solubility); therefore, Total Dissolved Solids (TDS) and ionic contents are linked to rock types. Soluble minerals are not found in metamorphic rock shields nor in volcanic rocks where silicates are more weathered. Hence waters tend to be low in TDS. TDS can, however, increase where hydrothermal groundwater inputs occur.

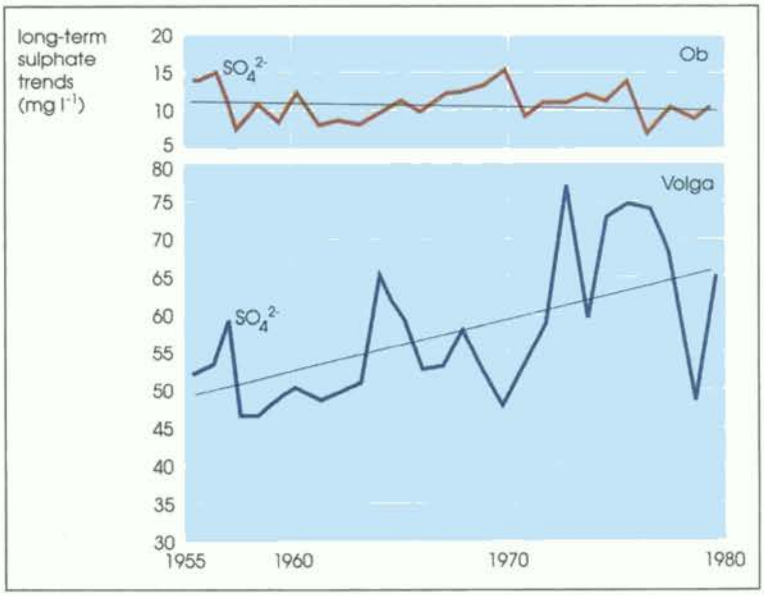
Sulphate

The sulphate ion (SO_4^{--}) is highly variable in surface waters where it is linked to sulphur-bearing minerals (Figure 25). Sulphate has greatly increased in some rivers (such as the St Lawrence and the Mississippi) over the past 100 years, largely as a result of increased industrial and agricultural activities (ref. 10 , 11 and 15). When sulphur-bearing minerals are more abundant as in the Great Plains shales, SO_4^{--} levels may exceed the 400 mg per litre WHO guideline for drinking water.

Development in the Ob River basin of Siberia has not affected sulphate concentrations (10 mg per litre) over the period for which records are available. The upper Ob basin is no longer pristine but SO_4^{--} concentration changes at the mouth are not significant enough to detect any sulphate pollution.

In comparison, even though natural background levels of SO_4^{--} in the Volga river are among the highest found for large rivers, SO_4^{--} has increased from 50 to 60 mg per litre since the 1950s. This is due to large-scale human activities, including mining and oil exploration.

Figure 27 Long-term trend of sulphate at the mouths of the Ob and Volga rivers in Russia (ref. 15, reproduced by permission).



Nutrients in surface waters

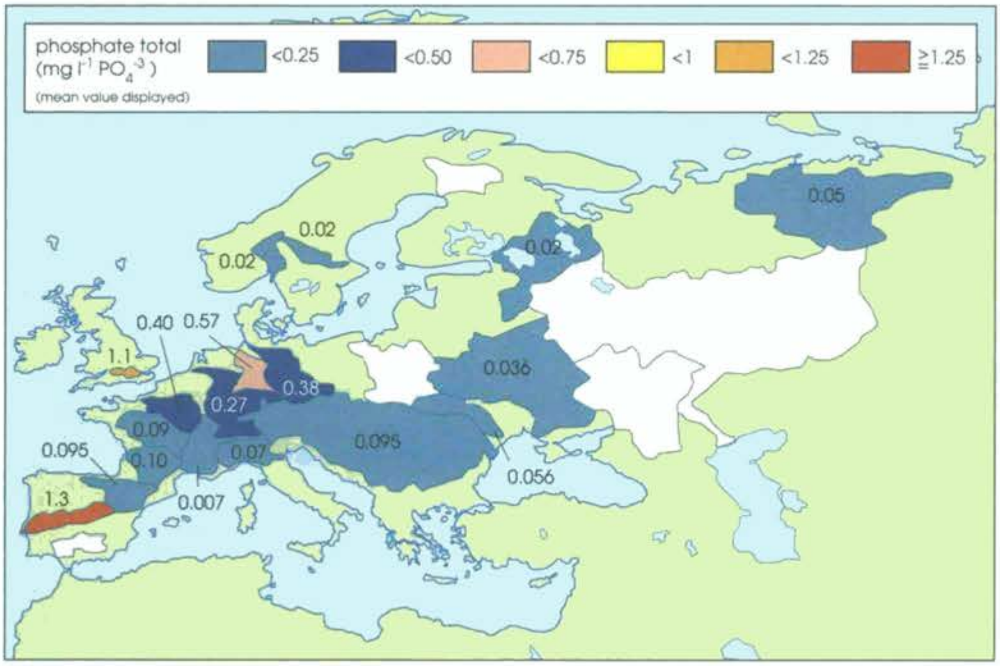


Figure 28 Phosphate concentration for major river basins in Europe.

Phosphorus and nitrogen

The primary nutrients, phosphorus (P) and nitrogen (N), are major constituents of agricultural fertilizer, animal wastes and municipal sewage. Runoff from agricultural lands and the discharge of municipal waste to rivers and lakes causes nutrient enrichment and leads to eutrophication of surface waters. Experience in phosphorus control strategies in North America and Europe has shown that, in some cases, lakes adversely affected by excessive levels of nutrients can be successfully reversed. Nitrate pollution in groundwater is becoming a major problem in many parts of the world.

Phosphorus and nitrogen, primarily in the oxidized forms of phosphate (PO_4^{-3}) and nitrate (NO_3^{-}), can be used as

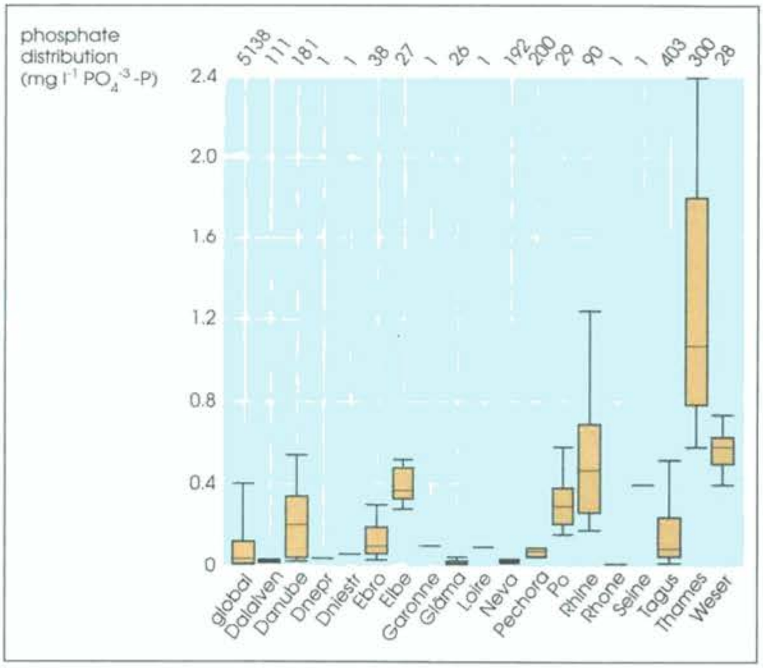


Figure 29 Statistical distribution of phosphate for major river basins in Europe (rivers with one sample value represent a yearly average at the river mouth).

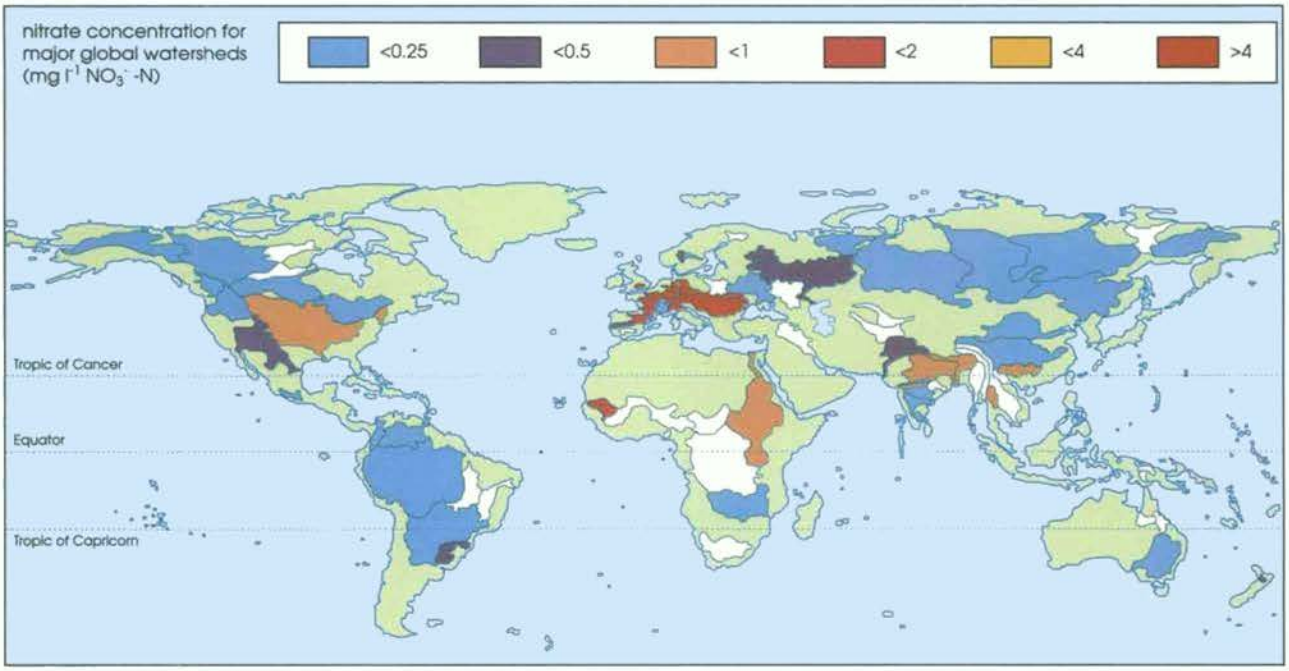


Figure 30 (above) Nitrate concentration for major global watersheds.

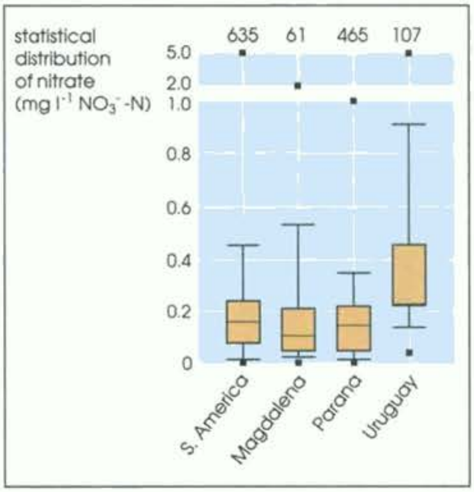


Figure 31 (right) Statistical distribution of nitrate in South American watersheds.

Figure 32 (below) Statistical distribution of nitrate for major global watersheds.

indicators both of population and agricultural impact on the environment. Higher concentrations of phosphate observed in some of the rivers of western Europe are indicative of municipal waste loading that has not received adequate treatment to remove phosphorus.

Nitrate and phosphate patterns in rivers are very site-specific and closely linked to hydrological variations. When NO$_3^-$ originates from fertilizers, as in Western Europe, higher levels are found in the winter when bare soils are leached by rain and melting snow. When NO$_3^-$ or PO$_4^{-3}$ originate from point sources, such as from urban sewage having only primary and secondary treatments, a marked dilution with discharge is observed. NO$_3^-$ and PO$_4^{-3}$ are also taken up by algae and aquatic weeds in reservoirs, lakes and rivers, which adds to the variance of these nutrients.

Beginning in the 1960s, efforts were made to collect and treat sewage in the Rhine basin. Controls on PO$_4^{-3}$ and NH$_4^+$ have been successful but NO$_3^-$ concentrations continue to increase slowly, principally due to the use of nitrogen-based fertilizers in the basin. This increase occurs in many other Western European rivers such as the Thames and Seine (ref. 18). Even if fertilizer inputs were drastically reduced, high NO$_3^-$ concentrations would

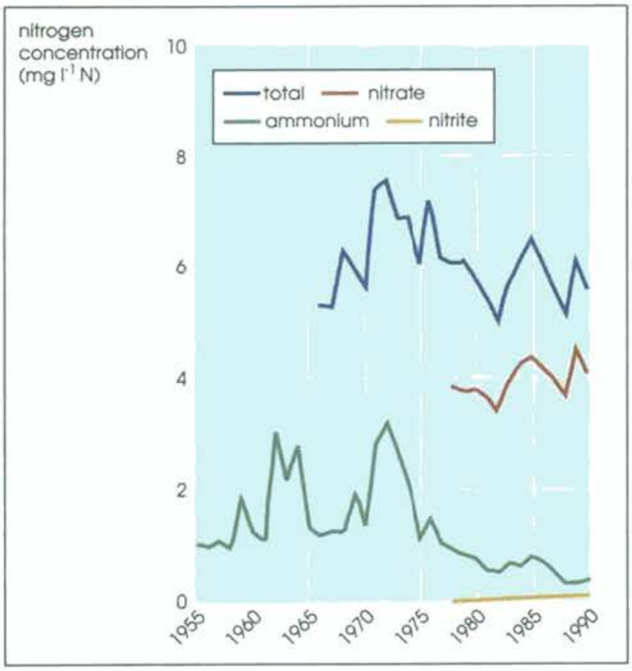


Figure 33 (top, left) Mean annual concentration of nitrogen species for the Rhine (ref. 31 reproduced by permission).

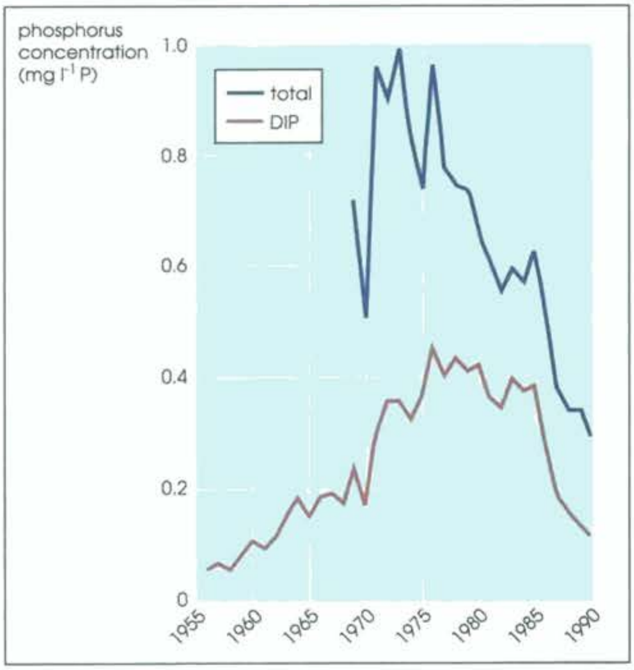


Figure 34 (top, right) Mean annual concentration of phosphorus species for the Rhine (ref. 31). DIP is Dissolved Inorganic Phosphorus. (reproduced by permission).

continue for 10 to 20 years before a decrease would be observed. It is expected that in many rivers, the WHO standard for drinking water (50 mg NO_3^- per litre) will be reached in the future.

Phosphate concentrations and seasonal ranges observed are very sensitive to domestic wastes and to intensive agriculture when phosphorus-based fertilizers are used. About half of the phosphate in urban sewage originates from phosphate-containing detergents and about half comes from human and animal wastes. The Murray River profile (Figure 35) illustrates this variability where upstream stations are nearly pristine and downstream locations are affected by polluting activities.

In most South American rivers, nitrate levels are reported to be very low, less than

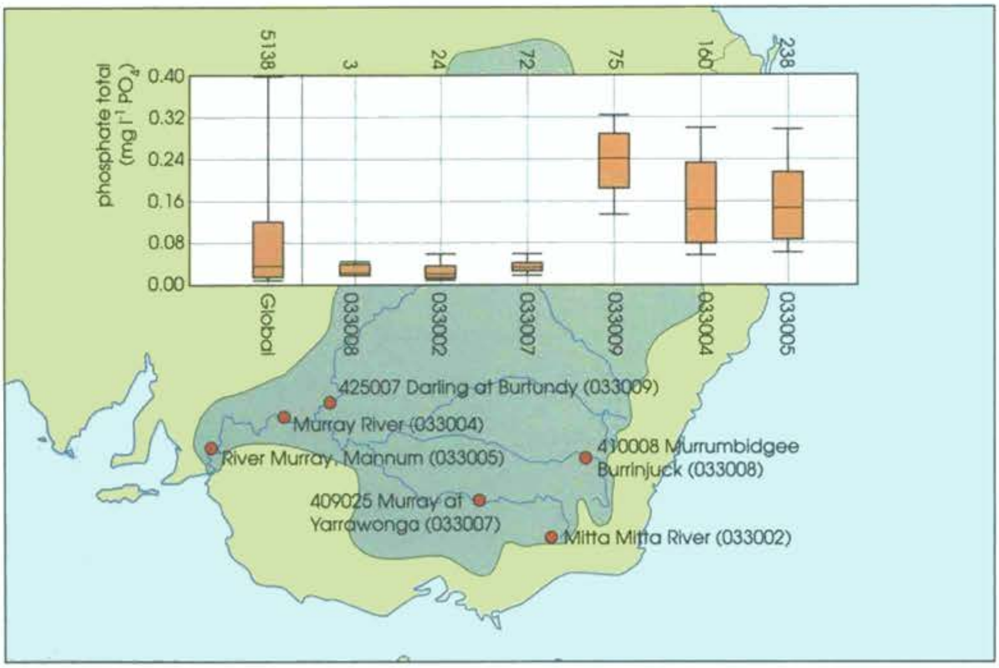


Figure 35 Longitudinal profile of phosphate in the Murray basin.

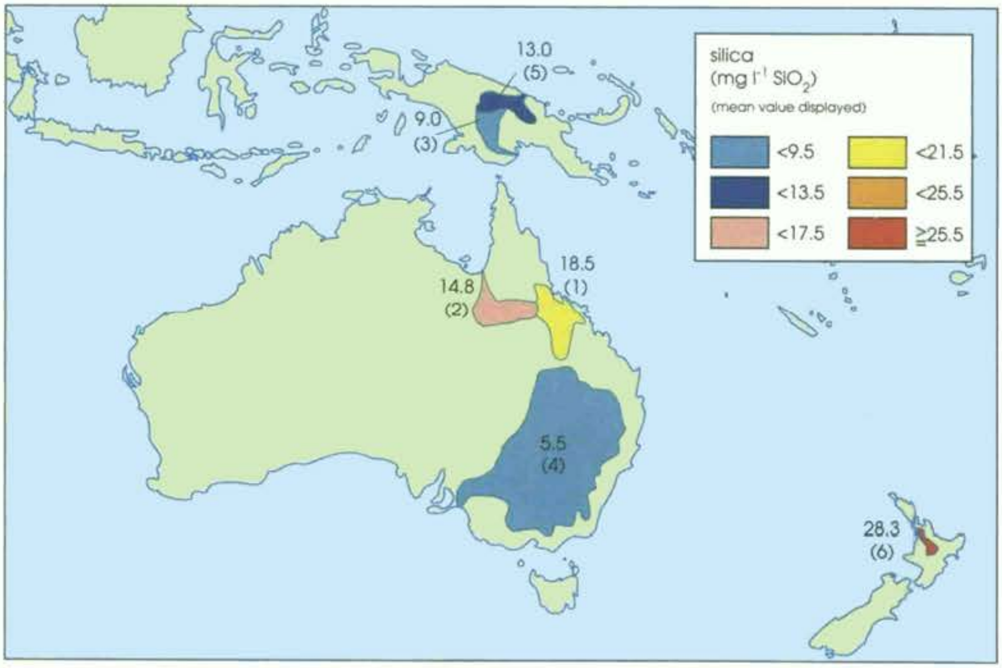


Figure 36 Silica variations of annual averages at river mouths in Oceania. Numbers in brackets identify watershed (see Table 6).

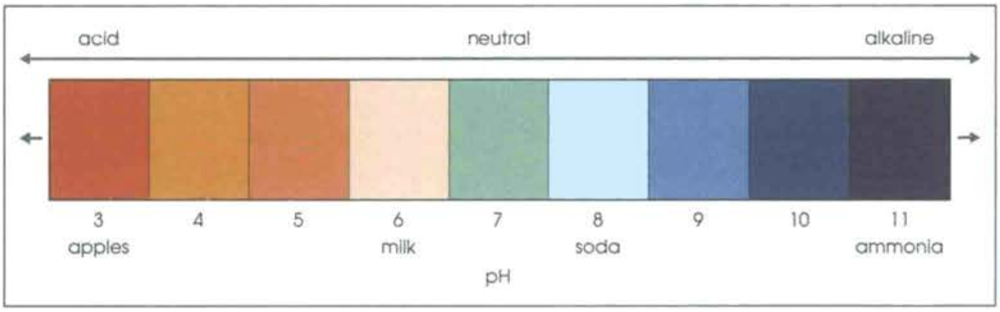
0.88 mg NO_3^- per litre. Similar levels are found in northern Canadian rivers, some Siberian rivers and most African rivers. In such rivers, nitrate is always a minor component of the ionic balance. Low NO_3^- concentration levels such as these are more than 50 times lower than the WHO standard for drinking water (50 mg NO_3^- per litre).

Silica

Silica is a key nutrient in diatom production, a very common algal group, and is taken up during the early growing season. SiO_2 concentrations can limit diatom production if concentrations become depleted in surface waters. This is particularly the case for lakes and reservoirs.

In rivers, dissolved silica concentrations depend primarily on the native rock types within a river basin. In the Oceania region, a maximum concentration occurs in basins with volcanic rocks such as the Waikato in New Zealand. Climate is also a factor with maximum concentrations found in warm areas such as the Flinders and Burdekin basins in north-eastern Australia. SiO_2 concentrations are lower for downstream lakes and reservoirs in Australia such as those located in the Murray-Darling basin.

Acidification of surface waters



Natural pH variations

Acidity is measured as pH which is a key parameter in water quality. pH is closely linked to biological productivity in aquatic systems and is a limiting factor for certain water uses. The pH scale is logarithmic, with a pH of 7.0 being neutral. Each whole unit on the scale represents a multiplication factor of 10. Thus, water with a pH of 5.0 is 100 times more acidic than water with a pH of 7.0.

In the absence of strong acid anions such as SO_4^{--} and NO_3^-, rain water is naturally acidic (pH = 5.7). This acidity is caused by the dissolution of atmospheric CO_2. After weathering reactions, natural pH levels in rivers are generally close to neutrality.

Most average annual pH values are between 6.5 and 8.3. Values of pH do not generally display strong variability at individual stations. In the GEMS/WATER data bank, the global median pH value is 7.7.

When weathering is limited and TDS are low, the major dissolved load is often dominated by dissolved organic acids resulting from soil leaching. Under these conditions pH values lower than 4.0 have been measured. Conditions such as this can be found downstream from peat bogs and other wetlands in many parts of the world. In Central Amazonia, and particularly within the Rio Negro basin, the so-called 'Black Waters' have a natural pH below 5.0. Other south American rivers are more neutral. African values used here come mostly from the Nile basin and are not representative of the whole continent.

In eutrophic rivers or downstream from lakes and reservoirs where chlorophyll maximums may exceed 100 mg m^{-3}, pH increases as a result of bicarbonate assimilation processes by aquatic plants. Values exceeding 8.5 are quite common in such waters. Under unusual conditions, pH values can increase and decrease by one pH unit in a single day and values can exceed

Figure 37 Global statistical distribution of pH.

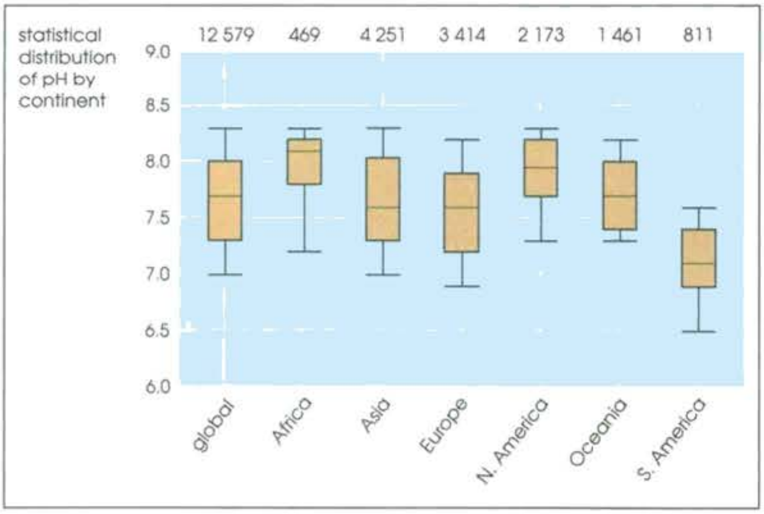
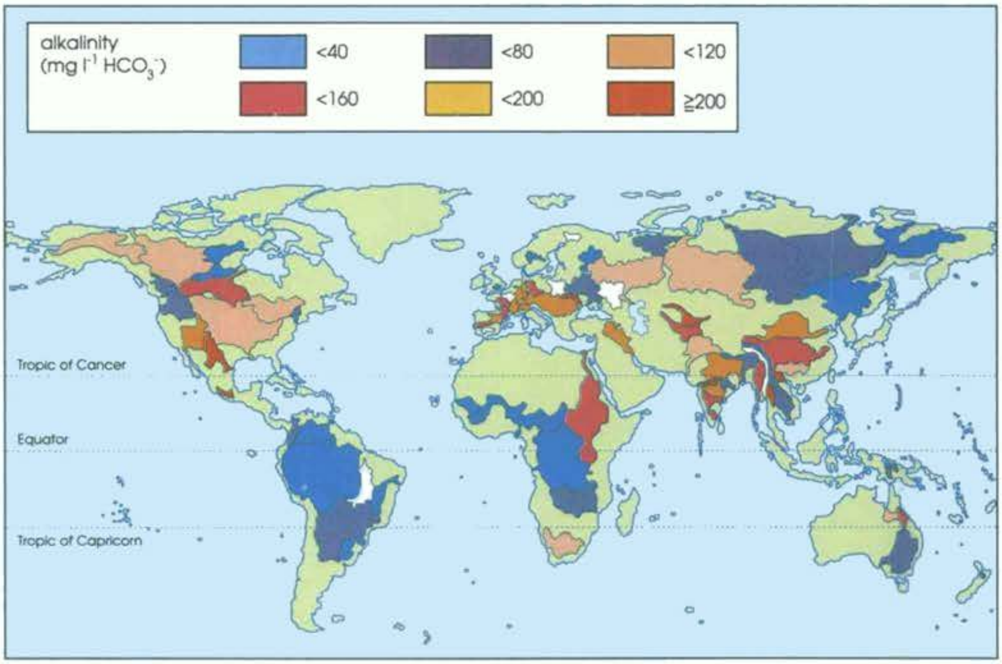


Figure 38 Global variation of average bicarbonate concentration at major river mouths.



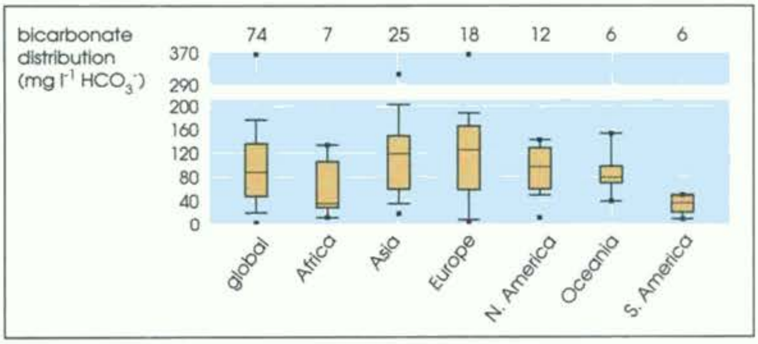


Figure 39 Bicarbonate statistical distribution by continent at major river mouths.

9.0 at midday. The Loire River (France) is an example of this kind of phenomenon where maxima of 200 mg m^{-3} of chlorophyll have been recorded. In rivers such as the Rhine, which are polluted by organic wastes, algal production is counter-balanced by bacterial degradation and the CO_2 concentration may keep the pH close to normal values (ref. 19).

Alkalinity

Within the usual range of pH values of rivers, from 6.4 to 8.3 (Figure 37), the bicarbonate ion (HCO_3^-) is the most common carbonate species found in natural waters. Concentrations of the bicarbonate ion are strongly related to Ca^{++} concentrations which reflect the weathering of limestones ($CaCO_3$) and dolomites ($CaCO_3$, $MgCO_3$). When these rocks are present the risk of acidification is low.

The distribution of bicarbonate (Figure 39) follows the same pattern as that of the Ca^{++} ion (Figure 18). In streams (surface areas of less than 100 km^2), HCO_3^- concentrations naturally range from 0 to 350 mg per litre, while in major rivers (surface areas more than 100 000 km^2), the concentration ranges from 10 to 170 mg per litre (ref. 4).

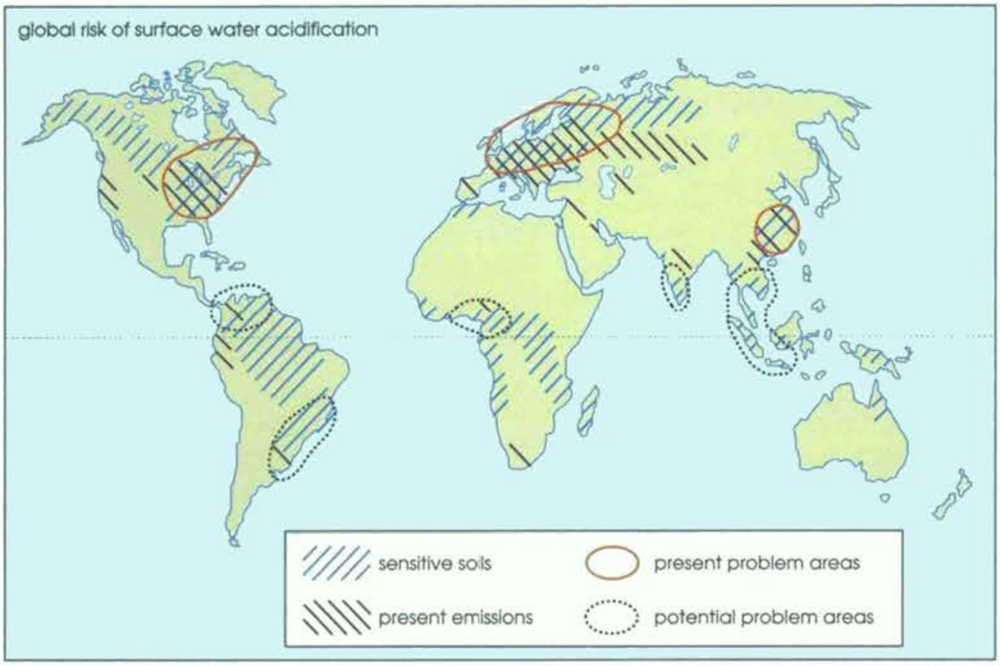


Figure 40 Global risk of surface water acidification (ref. 20, reproduced by permission).

Acidification

The natural acidity of rain water is increased by the presence of sulphur dioxide (SO_2) and nitrogen oxides (NO_X) which are atmospheric pollutants originating mainly from fossil fuel combustion. These compounds are likely to be carried by winds over long distances from urban, mining, thermo-electric power plants and industrial emission sources. During rainfall the acidic pollutants are washed out as sulphuric and nitric acids over vast areas and may affect pristine areas located hundreds or thousands of kilometres away from pollutant sources. Acidified waters are characterized by a major decrease in biological density and diversity.

Regional areas at risk from acid rain have been estimated by combining both the source areas (use of sulphur-bearing coal, major cities, oil refineries, various industries) and the occurrence of sensitive soils found in wet and humid regions (arid and semi-arid sensitive soils are not shown in Figure 40). Most crystalline shields and non-carbonated sedimentary rocks can be considered as being sensitive to acid precipitation. The presence of geologically sensitive areas downwind of existing major emission sources leads to three problem areas where acidification is a major issue: southern Scandinavia, north-eastern United States/eastern Canada, and eastern China. Projected rapid increases in emissions are likely to create future problem areas in Nigeria, India, Venezuela, southern Brazil and southeast Asia.

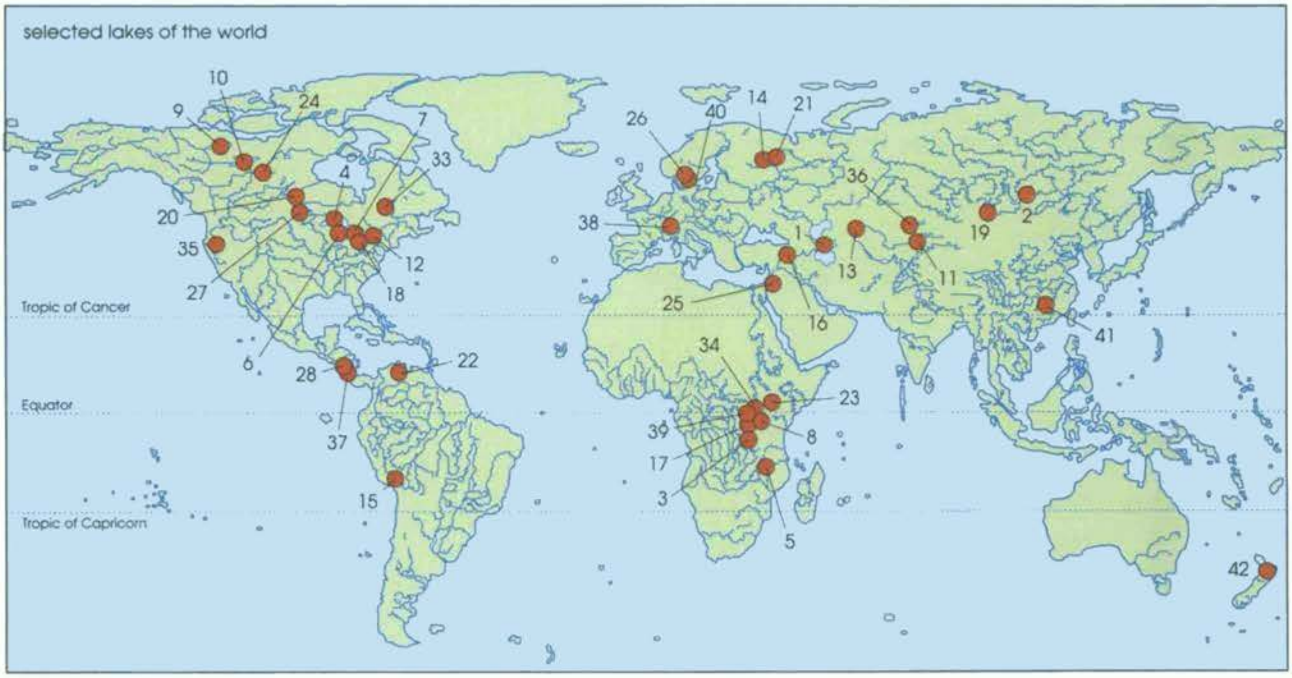
Water quality in lakes

Major world lakes have essentially two types of origin: one type is tectonic and includes the Caspian, Aral, Victoria, Baikal, Tanganyika and Malawi lakes. The second type is of glacial origin such as the Laurentian Great Lakes of North America, Ladoga, Vanern, Great Slave and Great Bear lakes. The first ranked 20 lakes in Table 7 represent 64 percent of the total lake area of the world (about 2.6 million km^2) and 91 percent of the total lake volume (about 179 000 km^3, of which 46 percent is saline). The Laurentian Great Lakes of North America and Lake Baikal in Russia each contain approximately 20 percent of the world's surface freshwater. Saline lakes (TDS more than 3 g per litre) have no outlets and are found in endorheic regions. Soft water lakes (TDS<300 mg per litre) are generally of the Ca^{++}/HCO_3^- type which dominates in most rivers. A few lakes, mostly fed by direct rain inputs, may have very low solute content (Tahoe and the Crater Lakes in western United States). Saline lakes may have very peculiar ionic composition (Na^+/HCO_3^-; Ca^{++}/SO_4^{--}; Mg^{++}/SO_4^{--}; Na^+/Cl^-) depending on crystallization of minerals during evaporation and on the chemical composition of their tributaries (ref. 8).

Lake eutrophication

Excessive nutrient concentrations, usually of phosphorus, lead to eutrophication of lakes. Eutrophication, especially in extreme cases, leads to algal blooms which are often followed by low oxygen levels when the algal material decays. High concentrations of algae cause taste and odour problems in drinking water, and some types of algae are toxic to animals.

Figure 41 Locations of selected lakes of the world (numbers refer to Table 7).



In the 1960s, excessive nutrient enrichment, especially in the Lower Great Lakes (Erie, Ontario) of North America and their connecting channels (Detroit, Niagara and St Clair rivers and Lake St Clair), led to the world's largest and most successful phosphorus control management scheme. During the 1970s, phosphorus was eliminated in detergents on both the US and the Canadian sides of the lakes, and strict controls were placed on the phosphorus content of effluents from sewage treatment plants. Phosphorus loadings were calculated so that phosphorus management could focus on the relative importance of point (sewage treatment) and non-point (mainly agricultural) sources.

Monitoring and assessment of all sources of phosphorus loads to Lake Erie over the past 20 years clearly show a decrease in loads to levels below the recommended standard established by the International Joint Commission (Figure 42).

Corresponding to the regulations restricting phosphorus loads to Lake Erie, comprehensive surveillance and monitoring programmes studying the chemistry and biology of the lake were undertaken. Concentrations of total phosphorus in Lake Erie have significantly reduced since 1970 (Figure 43). Prior to these controls Lake Erie was assessed as an eutrophic lake with frequent periods of anoxia in the bottom waters of the central basin. Serious concerns were expressed for the long-term health of the lake and for the economic viability of the fishery. Water quality management programmes have proven extremely effective in controlling and, in fact, reversing the trends in nutrient levels in the Great Lakes. Lake Erie has moved from eutrophic to mesotrophic status. Reductions in the frequency and occurrence of algal blooms, an improvement in the clarity of the water, and an improvement in the stocks of fish are amongst the benefits derived from the programme.

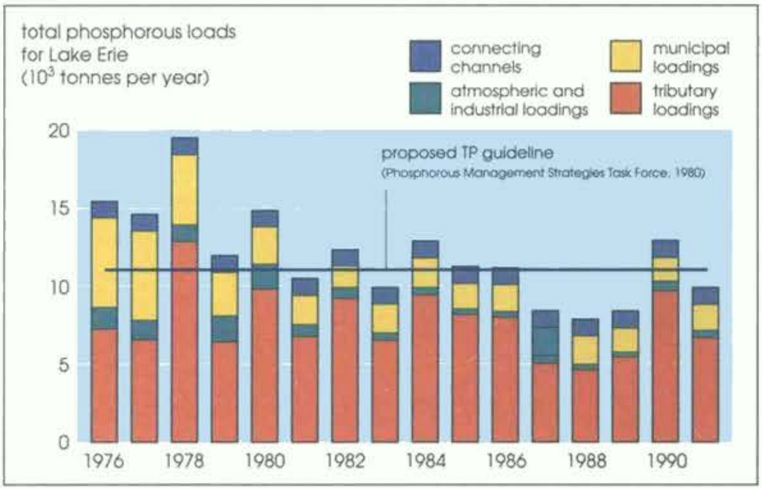


Figure 42 (top) Lake Erie total phosphorus loads (ref. 22, reproduced by permission).

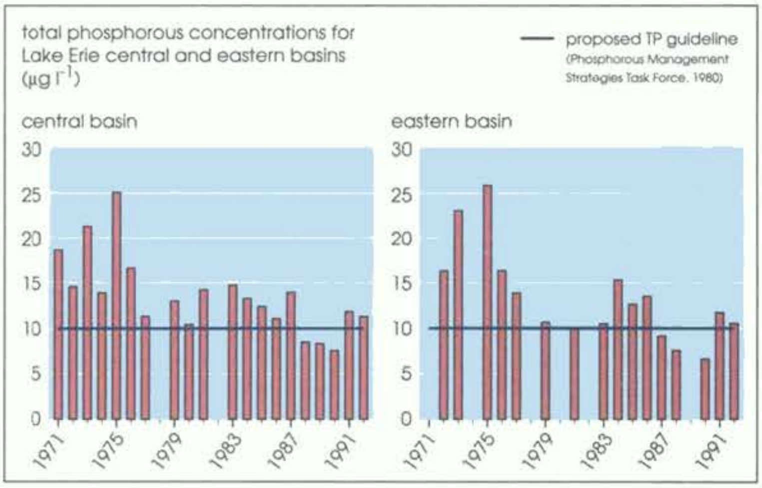


Figure 43 (bottom) Lake Erie total phosphorus concentrations (ref. 22, reproduced by permission).

Historical records for lake sediment

Sediment cores

The success of pollution remediation programmes is easily evaluated by comparing current with past levels of pollution. However, in many cases long-term records of pollution are lacking or of questionable validity. One method of obtaining an historical chronology of pollution is to examine sediment cores from receiving water bodies such as lakes, river deltas and reservoirs. Fine-grained sediment (silt and clay) trapped in the bottom of lakes and reservoirs preserves the historical nature and levels of many types of pollutants. Sediment cores can also be used to reconstruct lake pH conditions from planktonic material deposited with the sediment.

In the absence of long time-series of pH measurements in lakes, it is difficult to

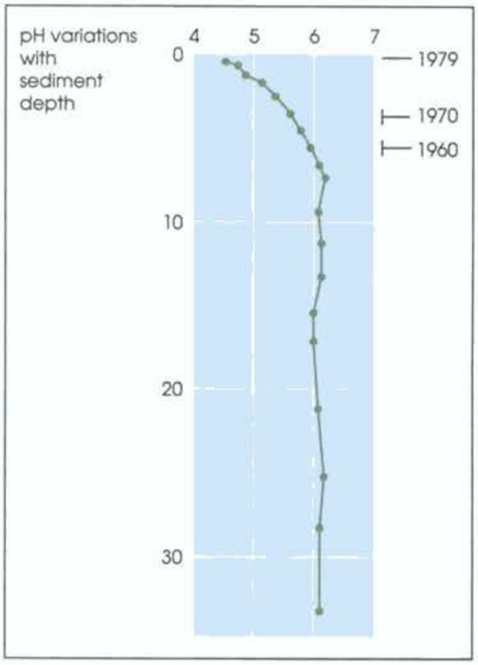


Figure 44 (right) Historical pH variations inferred from diatom assemblage in lake sediment (ref. 21, reproduced by permission).

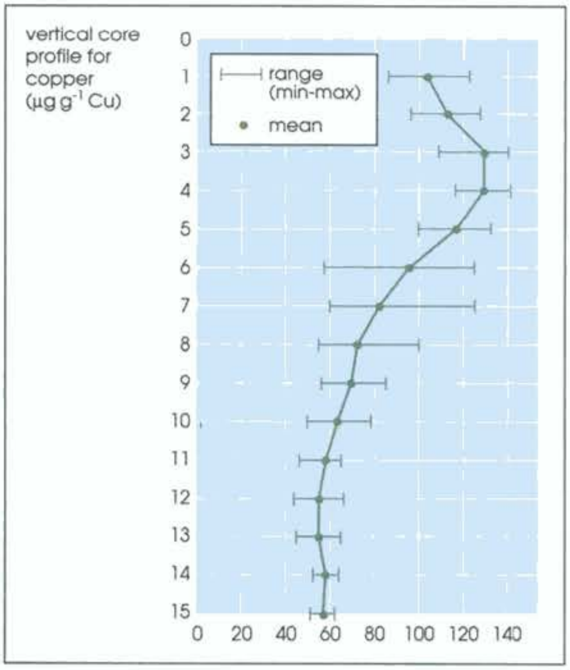


Figure 45 (below left) Vertical core profile for copper (Cu) in western Lake Ontario, 1987 (ref. 23, reproduced by permission).

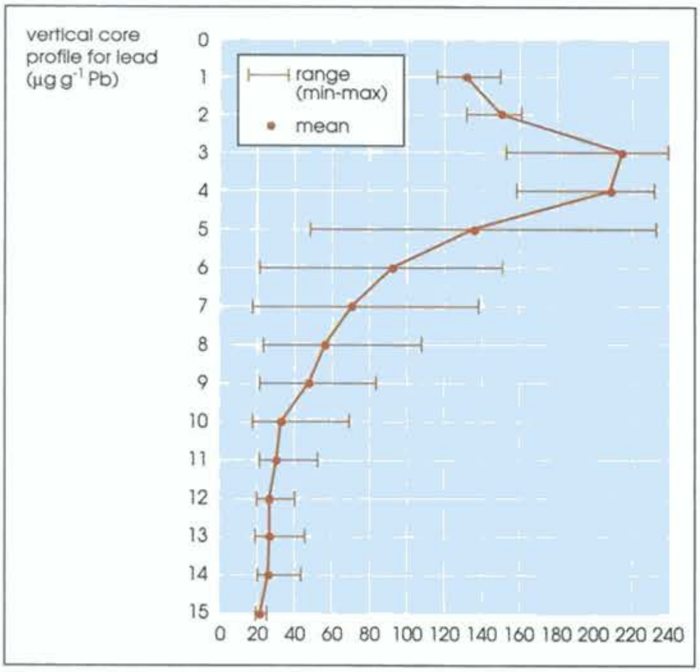
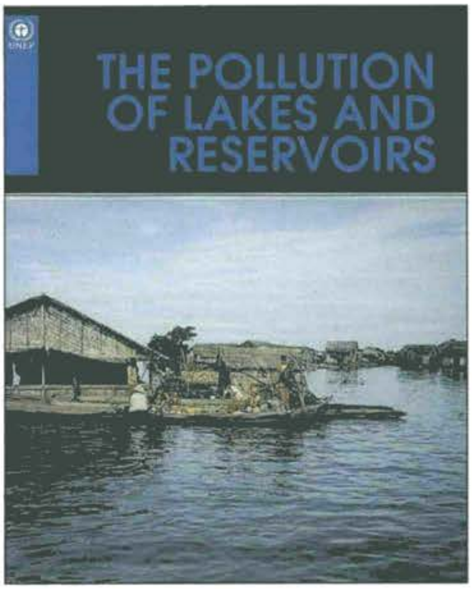


Figure 46 (below right) Vertical core profile for lead (Pb) in western Lake Ontario, 1985 (ref. 23, reproduced by permission).

reconstruct the historical record of acidification. Yet the careful study of diatom assemblages in numerous lakes of various acidities, together with lake sediment dating (for example, with the radioactive isotope ^{210}Pb) has led to a new method of historical pH reconstruction based on key alkaliphilous and acidophilous diatom species. This method is now currently used in countries such as the United Kingdom. In Lake Gardsjön, Sweden, an abrupt pH drop near 1960 marks the beginning of the acidification effect (Figure 44).

Studies of the sediments of Lake Ontario have shown that heavy metals such as copper (Cu) and lead (Pb) are associated with fine grain particulate matter. These particles are transported by currents and settle to the bottom sediments of the lake. Sediment cores taken from these areas show enrichment of heavy metals in the top 10 cm. (Figures 45 and 46). It is significant, however, that phosphorus control measures, especially the use of activated sludge and control of industrial sources, have had a significant and beneficial impact by reducing the discharge of metals. Metals have an affinity for sludge and are therefore removed as part of the treatment process. This can be seen in the surface layers of the sediment where copper and lead levels are declining (Figures 45 and 46).

UNEP has published a summary document on world lakes and reservoirs. The document highlights three major themes: the value of lakes and reservoirs, the deterioration of water resources and examples of prevention and restoration activities (ref. 29).



UNEP

THE POLLUTION OF LAKES AND RESERVOIRS

Biomonitoring

Biomonitoring is the measurement of effects of pollutants on natural aquatic test organisms ranging from bacteria to fish. Effects include mortality, growth inhibition, cancers and tumours, genetic alteration and reproductive failure. Effects can also be measured in the field by measuring species diversity. Biomonitoring also includes the measurement of pollutants that are accumulated in tissue and other organs of biological organisms.

Increasingly, water quality agencies are using a combination of standard chemistry and biomonitoring to improve understanding of levels and effects of pollutants. Figure 47 shows PCB concentrations measured in lake trout and in the shells of Lake Ontario herring gulls (note that the concentration scale is logarithmic). Elevated levels of PCBs in gull egg shells have the effect of thinning the shell and contributing to mortality. Studies of concentrations of PCBs in Lake Ontario show significantly decreasing trends in recent years. The presence of PCBs in fish has a cumulative impact (biomagnification) in the food chain, and leads to reproductive failure in top predators such as eagles and mink.

Figure 47 PCB concentrations in lake trout and herring gull eggs from Lake Ontario, Canada (reproduced by permission of Fisheries and Oceans Canada).

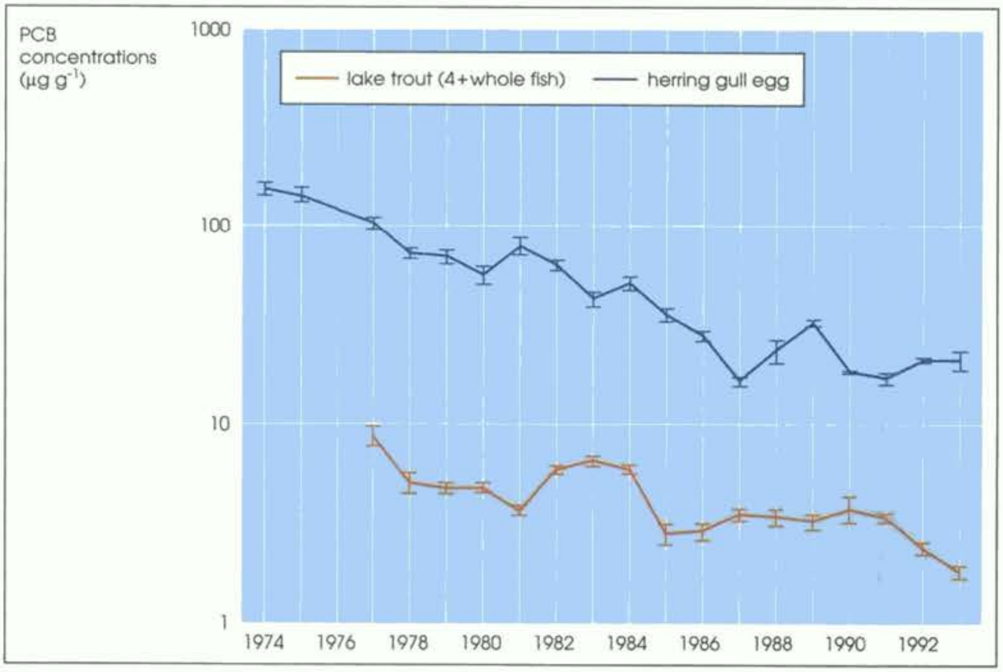


Table 1: General Characteristics of North American Rivers

													Concentration (mg l^{-1})					
	Watershed	Area	Discharge	Runoff	TDS	TDS(f)	TSS	TSS(f)	Na	K	Ca	Mg	Cl	SO_4	HCO_3	SiO_2	PO_4-P	NO_3-N
1	Balsas	0.116	16.3	141	682	11.1	–	–	33.3	7.6	218.0	20.7	21.9	62.8	317.8	–	0.20	0.19
2	Churchill	0.281	38.0	135	92	3.5	–	–	3.0	1.1	14.1	5.0	1.3	2.9	61.7	3.0	–	–
3	Colombia	0.669	250.0	374	147	36.6	40	10.0	7.3	1.5	20.7	5.4	3.6	16.5	81.0	10.5	0.03	0.11
4	Colorado	0.715	0.5	1	703	0.4	200	0.1	95.0	5.0	83.0	24.0	82.0	270.0	135.0	9.3	0.10	0.30
5	Fraser	0.228	112.0	491	93	10.5	179	20.0	1.6	0.8	16.0	2.5	0.1	7.6	60.0	4.9	0.05	0.09
6	Hudson	0.035	17.3	557	100	1.2	85	1.0	–	–	22.0	4.0	12.0	–	61.6	–	–	0.59
7	Mackenzie	1.745	333.0	191	209	69.5	126	42.0	7.6	1.0	35.6	8.2	7.9	35.4	110.0	3.0	0.04	0.14
8	Mississippi	3.270	580.0	177	287	166.7	362	210.0	21.5	3.1	40.7	11.3	25.1	54.1	124.0	7.6	0.20	1.06
9	Nelson	1.115	110.0	99	281	30.9	–	–	24.0	2.4	32.6	13.6	30.2	31.4	144.0	2.6	0.05	0.03
10	Rio Grande	0.670	3.2	5	–	–	254	0.8	–	–	–	–	–	–	–	–	–	0.29
11	St. Lawrence	1.020	337.0	330	183	61.7	12	4.0	11.0	1.8	31.0	4.0	22.0	24.0	87.0	2.4	0.02	0.22
12	Thelon/Kazan	0.213	43.7	205	24.8	1.08	–	–	0.7	0.4	4.5	1.0	3.3	1.9	13.0	0.5	–	–
13	Yukon	0.860	210.0	244	183	38.4	286	60.0	2.6	1.2	31.8	7.2	1.1	22.4	109.0	7.7	0.01	0.12

See footnote for explanation of terms

Table 2: General Characteristics of South American Rivers

													Concentration (mg l^{-1})					
	Watershed	Area	Discharge	Runoff	TDS	TDS(f)	TSS	TSS(f)	Na	K	Ca	Mg	Cl	SO_4	HCO_3	SiO_2	PO_4-P	NO_3-N
1	Amazon	6.112	6450	1055	43.5	280.6	186	1200	1.9	0.8	5.4	0.9	2.2	4.5	21.0	6.9	0.02	0.17
2	Magdalena	0.276	237	859	118.2	28.0	928	220	8.3	1.9	15.0	3.3	13.4	14.4	49.3	12.6	0.12	0.25
3	Orinoco	1.100	1135	1032	24.8	28.2	132	150	1.5	0.7	2.6	0.7	0.9	2.3	10.0	6.3	0.01	0.08
4	Parana	2.600	523	201	98.5	51.5	151	79	10.4	2.5	5.4	3.4	14.3	4.1	35.4	23.0	0.07	0.03
5	Sao Francisco	0.630	90	143	65.7	5.9	67	6	–	–	8.0	–	2.5	2.5	50.6	2.2	–	–
6	Tocantins	0.750	372	496	–	–	202	75	–	–	–	–	–	–	–	–	0.003	0.015
7	Uruguay	0.240	145	443	75.2	10.9	76	11	5.0	2.0	7.0	2.0	3.0	5.0	36.2	15.0	0.02	0.30

See footnote for explanation of terms

Data are compiled for individual watersheds and aggregated to regional values for average values.

Area	Basin Area 10^6 km^2	Discharge	River Discharge, km^3 year^{-1}
Runoff	Runoff, mm year^{-1}	TDS	Total Dissolved Solids, mg l^{-1} (calculated as sum of major ions)
TSS	Total Suspended Sediment, mg l^{-1} (calculated)	–	Missing Data
TDS(f)	Annual Load of TDS to Oceans, 10^6 tonnes year^{-1}	°	Calculated from Median
TSS(f)	Annual Load of TSS to Oceans, 10^6 tonnes year^{-1} (ref.7)		

* These watersheds do not drain into oceans and are excluded from continental and global summations of discharge and flux.

Table 3: General characteristics of Asian rivers

									Concentration (mg l^{-1})									
	Watershed	**Area**	**Discharge**	**Runoff**	**TDS**	**TDS(f)**	**TSS**	**TSS(f)**	**Na**	**K**	**Ca**	**Mg**	**Cl**	**SO_4**	**HCO_3**	**SiO_2**	**PO_4-P**	**NO_3-N**
1	Amu Daria*	0.231	38.5	64	368	10.6	3275	94.0	10.0	1.4	89.5	3.2	45.4	78.4	140.4	–	–	–
2	Amur	1.920	355.0	169	73	25.8	146	52.0	2.9	1.0	10.1	2.6	2.3	5.0	42.7	6.0	0.035	0.12
3	Brahmaputra	0.580	630.0	1087	99	62.2	857	540.0	2.1	1.9	14.0	3.8	1.1	10.0	58.0	7.8	0.060	0.82
4	Cauveri	0.087	21.0	241	396	8.3	2	0.04	60.0	5.5	28.0	24.0	50.0	32.0	177.0	19.0	–	0.03
5	Chang Jiang	1.830	873.0	477	221	192.9	550	480.0	5.1	1.4	38.9	7.1	5.3	15.7	141.0	6.5	0.014	0.77
6	Chao Phrya	0.110	27.8	253	192	5.3	396	11.0	1.3	0.9	38.4	4.6	1.2	7.7	131.0	6.6	–	0.65
7	Ganges	0.950	460.0	619	156	71.9	1130	520.0	6.4	2.5	22.0	4.9	3.1	5.6	104.0	7.7	0.075	0.86
8	Godavari	0.310	92.0	350	214	19.7	1848	170.0	18.0	2.5	21.2	8.6	12.7	7.0	131.0	13.1	–	0.19
9	Hong He	0.165	123.0	745	148	18.2	1057	130.0	11.1	1.5	16.5	8.1	8.3	11.4	81.0	10.0	–	–
10	Huang He	0.770	35.0	45	460	16.1	26470	900.0	54.5	4.1	47.0	20.6	54.7	66.8	205.0	7.7	0.016	0.17
11	Indigirka	0.356	59.0	166	49	2.9	237	14.0	4.3	1.0	5.5	1.6	2.5	9.3	18.8	5.9	–	–
12	Indus	0.920	50.0	54	240	12.0	1187	59.0	32.0	6.9	35.0	16.0	32.0	40.0	65.0	14.0	0.130	0.40
13	Irrawady	0.414	428.0	1034	201	86.0	607	260.0	30.0	2.0	10.0	6.0	18.0	5.0	120.0	10.0	–	–
14	Kolyma	0.647	135.0	205	77	10.4	44	6.0	0.2	0.1	11.6	2.4	0.3	4.8	54.0	4.0	–	0.05
15	Krishna	0.252	67.0	266	322	21.6	239	16.0	54.0	2.0	25.0	11.0	39.0	21.0	168.0	5.0	–	0.16
16	Lena	2.440	533.0	214	112	59.6	23	12.0	4.5	0.7	17.1	5.1	12.0	13.5	53.1	5.8	0.010	0.09
17	Mahanadi	0.132	66.0	500	147	9.7	909	60.0	10.2	1.5	10.4	9.5	30.9	15.0	60.9	9.0	–	–
18	Mekong	0.795	510.0	642	99	50.4	294	150.0	3.6	2.0	14.2	3.2	5.3	3.8	57.9	8.9	–	–
19	Narmada	0.102	40.7	452	327	13.3	3071	125.0	27.0	2.0	14.0	20.0	25.0	5.0	225.0	9.0	0.020	0.12
20	Ob	2.550	419.0	140	140	58.7	38	16.0	4.0	3.0	21.0	5.0	10.0	9.0	79.0	9.0	0.060	0.09
21	Salween	0.325	211.0	649	–	–	–	–	–	–	–	–	–	–	–	–	–	–
22	Shatt El Arab	0.750	77.0	136	400	30.8	1364	105.0	31.0	3.0	52.0	22.0	32.0	73.0	180.0	6.9	0.010	–
23	Syr Daria*	0.219	21.5	–	545	3.7	1364	12.0	31.2	3.7	93.5	20.0	32.6	161.4	202.8	–	–	–
24	Tapti	0.062	18.0	290	488	11.7	1372	24.7	65.0	2.0	32.0	23.5	59.7	5.0	285.0	16.0	–	0.60
25	Xi Jiang	0.442	316.0	651	192	60.8	218	69.0	1.3	0.9	38.4	4.5	1.2	7.7	132.0	6.5	0.004	0.60
26	Yennissei	2.550	562.0	220	127	71.5	23	13.0	1.5	0.8	21.0	4.1	9.0	8.6	74.0	8.3	0.010	0.10

See footnote for explanation of terms

Table 4: General characteristics of African rivers

									Concentration (mg l^{-1})									
	Watershed	**Area**	**Discharge**	**Runoff**	**TDS**	**TDS(f)**	**TSS**	**TSS(f)**	**Na**	**K**	**Ca**	**Mg**	**Cl**	**SO_4**	**HCO_3**	**SiO_2**	**PO_4-P**	**NO_3-N**
1	Chari*	0.60	41.6	69	68	2.8	58	2.4	2.8	1.6	3.9	1.6	2.0	2.0	29.8	24.0	–	–
2	Niger	1.24	168.0	135	65	11.0	238	40.0	1.8	1.1	5.5	1.9	0.9	0.5	39.5	14.0	–	–
3	Nile	2.96	30.0	10	204	6.1	–	–	8.1	3.2	22.0	5.3	5.7	12.0	135.0	12.8	0.03	0.80
4	Orange	1.02	15.3	15	183	2.8	1111	17.0	13.4	2.3	18.1	7.8	10.6	7.2	107.0	16.9	–	0.72
5	Senegal	0.27	10.4	39	55	0.6	183	1.9	2.2	1.2	3.9	2.9	1.0	2.4	29.5	11.9	–	–
6	Zaire	3.69	1350.0	366	42	56.1	32	43.0	2.17	1.55	2.67	2.07	3.32	1.5	17.1	11.2	–	–
7	Zambezi	1.25	103.0	82	140	14.5	194	20.0	5.4	1.9	12.9	4.1	6.5	5.0	89.0	15.5	–	0.13

See footnote for explanation of terms

Table 5: General characteristics of European rivers

									Concentration (mg l^{-1})								
	Watershed	Area	Discharge	Runoff	TDS	TDS(f)	TSS	TSS(f)	Na	K	Ca	Mg	Cl	SO_4	HCO_3	SiO_2	PO_4-P	NO_3-N
1	Dalalven	0.029	9.8	338	24	0.2	-	-	1.4	0.6	3.8	0.7	1.1	8.0	8.2	4.8	0.004	0.113
2	Danube	0.817	214.0	262	307	65.6	313	67.0	9.0	1.0	49.0	9.0	19.5	24.0	190.0	5.0	0.10	-
3	Dnepr	0.504	52.0	103	174	9.1	40	2.1	8.0	3.0	22.5	7.5	15.2	35.8	78.6	3.4	0.01	0.2
4	Dniestr	0.072	9.6	133	813	7.8	261	2.5	70.0	6.0	108.0	35.0	82.6	139.0	368.0	4.1	0.1	1.0
5	Don	0.420	28.9	69	-	-	27	0.8	-	-	-	-	-	-	-	-	-	-
6	Ebro	0.087	17.4	200	517	9.0	86	1.5	75.5	2.0	75.0	15.7	72.5	133.5	131.7	10.6	0.037	1.50
7	Elbe	0.148	22.8	154	612	14.0	37	0.8	85.5	26.1	107.0	16.1	174.0	153.0	132.0	4.0	0.38	3.0
8	Garonne	0.055	19.9	362	227	4.5	57	1.1	8.0	1.5	43.8	6.0	12.1	18.6	133.0	4.0	0.10	1.5
9	Glåma	0.040	18.9	473	29	0.5	-	-	1.2	0.8	4.7	0.7	1.4	5.1	15.1	-	0.008	0.42
10	Guadalquivir	0.056	7.3	129	816	5.9	-	-	105.0	7.0	100.0	33.0	160.0	163.0	233.0	15.0	-	-
11	Kemijoki	0.052	13.7	263	34	0.5	11	0.2	1.9	0.8	4.4	1.1	2.1	3.8	19.5	-	-	-
12	Loire	0.120	27.4	228	233	6.4	16	0.5	13.1	3.6	39.0	6.0	20.0	23.0	120.0	8.0	0.1	1.7
13	Neva	0.281	82.6	294	63	5.1	6	0.5°	3.0	1.5	9.8	2.5	6.8	9.6	29.4	0.2	-	0.29
14	Pechora	0.248	136.0	548	101	13.7	48	6.5	5.6	0.9	15.6	3.8	5.6	9.5	60.0	2.9	0.003	0.007
15	Po	0.070	46.7	667	354	16.5	278	13.0	16.8	3.0	62.1	11.9	18.1	60.1	178.0	4.0	0.084	1.4
16	Rhine	0.220	74.5	339	600	44.7	-	0.7	91.9	6.4	80.5	11.4	173.0	74.0	158.0	5.2	0.4	3.88
17	Rhone	0.096	49.5	516	339	16.8	626	31.0	11.3	2.1	70.8	6.5	22.4	46.0	176.0	4.0	0.01	0.01
18	Seine	0.065	12.9	198	487	6.3	85	1.1	21.2	4.9	105.0	9.2	38.5	55.7	252.0	-	0.40	4.30
19	Tagus	0.076	9.6	126	326	3.1	18	0.2°	28.3	2.7	45.4	15.4	41.8	97.0	95.0	10.4	1.31	0.66
20	Thames	0.015	3.2	207	392	1.10°	14	0.1°	28.7	5.9	-	5.4	39.0	61.2	4.8	12.2	1.07	-
21	Vistula	0.198	31.8	161	-	-	79	2.5	-	-	-	-	-	-	-	-	-	-
22	Volga*	1.350	214.0	159	299	63.9	117	25.0	17.9	1.6	50.2	9.9	18.9	62.1	134.0	4.0	0.02	0.62
23	Weser	0.046	10.6	231	2463	26.1	31	0.3	574.0	42.0	56.0	151.0	1233.0	235.0	168.0	4.0	0.57	4.95

See footnote for explanation of terms

Table 6: General characteristics of Oceania rivers

									Concentration (mg l^{-1})								
	Watershed	Area	Discharge	Runoff	TDS	TDS(f)	TSS	TSS(f)	Na	K	Ca	Mg	Cl	SO_4	HCO_3	SiO_2	PO_4-P	NO_3-N
1	Burdekin	0.1290	8.5	66	280	2.4	355	3.0	32.5	3.2	23.0	12.8	34.0	1.1	155.0	18.5	-	-
2	Flinders	0.1090	2.0	18	147	0.3	-	-	13.0	4.0	14.0	4.9	10.5	4.3	81.0	14.8	-	-
3	Fly	0.0610	141.0	2203	116	16.3	816	115.0	2.3	0.4	21.3	1.8	0.1	2.7	78.3	9.0	-	-
4	Murray Darling	1.1400	7.9	7	453	3.6	3797	30.0	101.0	6.0	21.0	17.0	171.0	38.0	94.0	5.0	0.1	0.03
5	Sepik	0.0787	120.0	1525	112	13.4	68	8.2	3.0	0.4	15.0	4.0	0.5	5.0	71.0	13.0	-	-
6	Waikato	0.0137	12.8	934	128	1.6	14	0.2°	18.6	3.2	7.0	2.3	19.2	7.2	42.0	28.4	0.1	0.30

See footnote for explanation of terms

Table 7: Physicaland Chemical Data for Selected Lakes of the World (ref. 27, ref. 28)

	Name	Area km^2	Volume km^3	Maximum Depth m	Residence Time (years)	TDS mg l^{-1}	Na mg l^{-1}	K mg l^{-1}	Ca mg l^{-1}	Mg mg l^{-1}	SO$_4$ mg l^{-1}	Cl mg l^{-1}	HCO$_3$ mg l^{-1}	SiO$_2$ mg l^{-1}	PO$_4$-P mg l^{-1}	NO$_3$-N mg l^{-1}
1	Caspian	374000	78200	1025	250	12666	3096	67.0	381	756	3000	5280	83	2.5	-	-
2	Baikal	31500	22995	1740	350	99	3.6	1.0	16.1	3.05	5.5	0.44	66.6	2.9	-	-
3	Tanganyika	32900	18900	1471	500	521	66.3	34.2	8.2	43.5	3.4	21	344	-	0.007	0.07
4	Superior	82800	12230	407	180	72	1.1	0.6	12.4	2.8	3.2	1.9	50	-	0.003	0.26
5	Malawi	22490	6141	706	150	203	20.9	6.3	19.8	4.7	5.3	4.2	142	-	-	-
6	Michigan	57750	4920	282	80	201	3.4	0.9	32	10.0	15.5	6.2	130	3.1	0.010	0.09
7	Huron	59500	3537	229	23	161	3.2	0.8	28.1	6.7	17.2	6.3	95.9	2.3	0.005	0.23
8	Victoria	68460	2700	92	23	88	10.4	3.8	5.6	2.6	2.3	3.9	56.1	3.0	-	-
9	Great Bear	31326	2381	452	110	120	4.2	0.8	16.2	6.9	14.8	4.8	68	4.6	-	-
10	Great Slave	28568	2088	625	8	147	6.7	0.9	26.8	5.3	15	6.7	85.9	-	-	-
11	Issyk Kul	6240	1730	702	500	5855	-	-	-	-	-	-	-	-	-	-
12	Ontario	19000	1637	245	8	233	12.6	1.4	40.3	8.1	29.4	27.5	113.2	0.3	0.008	0.35
13	Aral *	64100	1020	68	20	10500	-	-	-	-	-	-	-	-	-	-
14	Ladoga	17700	908	230	13	53	3.0	1.5	9.8	2.5	6.8	9.6	29.4	-	-	-
15	Titicaca	8030	827	304	80	832	176	14.0	66	34	282	260	-	-	-	-
16	Van	3740	607	457	80	16382	7747	508.0	7	95	2344	5450	231	-	-	-
17	Kivu	2370	569	480	200	1151	121.6	97.0	4.8	87	23.8	55	762	-	-	-
18	Erie	25657	483	64	2.6	223	11.5	1.2	37.4	8.3	25.7	24.6	112.8	1.5	0.015	-
19	Hovsgol	2620	480	270	560	-	-	-	-	-	-	-	-	-	-	-
20	Winnipeg	24387	371	18	3.5	165	6.0	2.0	20	8.6	3	5.2	116	4.1	-	-
21	Onega	9700	295	127	16	-	-	-	-	-	-	-	-	-	-	-
22	Maracaibo	13010	280	60	-	-	-	-	-	-	-	-	-	-	-	-
23	Turkana	8660	237	114	14	2340	742	20.9	4.4	2.4	38.5	447	1067	18.0	-	-
24	Athabaska	7935	204	120	-	84	3.3	0.9	3.4	32	5.1	3.3	36.2	-	-	-
25	Dead	1020	188	433	125	309040	34940	7560	15800	41960	540	208000	240	-	-	-
26	Vanern	5648	153	106	9	153	-	-	-	-	-	-	-	-	0.010	0.85
27	Manitoba	4625	17	4	-	-	-	-	-	-	-	-	-	-	-	-
28	Managua	1040	33	80	-	-	-	-	-	-	-	-	-	-	-	-
33	Mistassini	2335	175	183	-	-	-	-	-	-	-	-	-	-	-	-
34	Albert	5590	151	58	-	715	91	65.0	9.8	32.1	36.5	33	447	0.9	0.160	0.02
35	Tahoe	500	124	501	250	64	6.1	1.7	9.4	2.5	2.5	1.9	40	-	0.006	0.02
36	Balkash	18200	112	26	6	-	-	-	-	-	-	-	-	-	-	-
37	Nicaragua	8150	108	70	-	119	11	2.0	16	6	-	19	65	-	-	-
38	Geneva	580	89	310	-	204	2.2	1.4	44	5.5	44.3	2.5	102	2.5	0.080	0.50
39	Edward	2150	78	117	-	933	110	91.0	11.4	48.3	42.8	36.5	593	-	-	-
40	Vattern	1856	74	128	55	81	-	-	-	-	-	-	-	-	0.005	0.65
41	Dong Ting Yu	2740	18	31	0.5	-	-	-	-	-	-	-	-	-	0.002	0.40
42	Taupo	616	59	165	12	100	15.2	2.2	6.5	2.3	5.65	9.2	44.7	14.2	0.008	2.20

Note: Lakes in this table are ranked in order of lake volume for lakes with volumes greater than 200 km^3. * Aral figures valid for 1950.

Glossary

Aeolian Loess:	Deposit of wind driven fine particles
Acidophilous:	Preferring or thriving in a relatively acid environment
Alkaliphilous:	Preferring or thriving in a relatively alkaline environment
Amorphous:	Not composed of crystals in a physical structure
Anions:	Negatively charged element or compound
Anthropogenic:	Related to human activities
BOD:	Biochemical Oxygen Demand
Cations:	Positively charged element or compound
CCIW:	Canada Centre for Inland Waters, Burlington, Ontario, Canada
COD:	Chemical Oxygen Demand
Diatom:	Unicellular algae with silicified cell walls
Endorheic:	Interior drainage, flow does not go to the ocean
Eutrophication:	High degree of biological nutrition
Evapotranspiration:	Moisture loss to the atmosphere from plants by transpiration and evaporation
GEMS:	Global Environment Monitoring System
Macrophytes:	Rooted aquatic plants
Mesotrophic:	Medium degree of biological nutrition
Orography:	Relating to the relief features of mountains
Phytoplankton:	Microscopic and macroscopic floating or drifting plant life including algae
RAISON:	Computer software package used in GEMS/WATER
TDS:	Total Dissolved Solids (sum of major ions and dissolved silica)
Thermocline:	Transition zone of rapid temperature change
TSS:	Total Suspended Solids
Turbidity:	Cloudiness of a liquid caused by suspended matter
Weathering:	Physical and chemical breakdown of rocks due to natural processes
WHO:	World Health Organization

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