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European Rivers and Lakes

Assessment of their Environmental State

European Environment Agency
EEA Environmental Monographs 1

European Rivers and Lakes
– Assessment of their Environmental State

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Cover picture: Michael St. Maur Sheil©

Printed by: Silkeborg Bogtryk, Silkeborg, Denmark

Published by: European Environment Agency,
Copenhagen, 1994

ISBN: 87-90198-01-8
ISSN: 0909-9468

Price: 150 DKK (excluding VAT)

For sale at:
European Environment Agency,
Kongens Nytorv 6
DK–1050 Copenhagen K, Denmark
Tel: + 45 33 14 50 75
Fax: + 45 33 14 65 99

or

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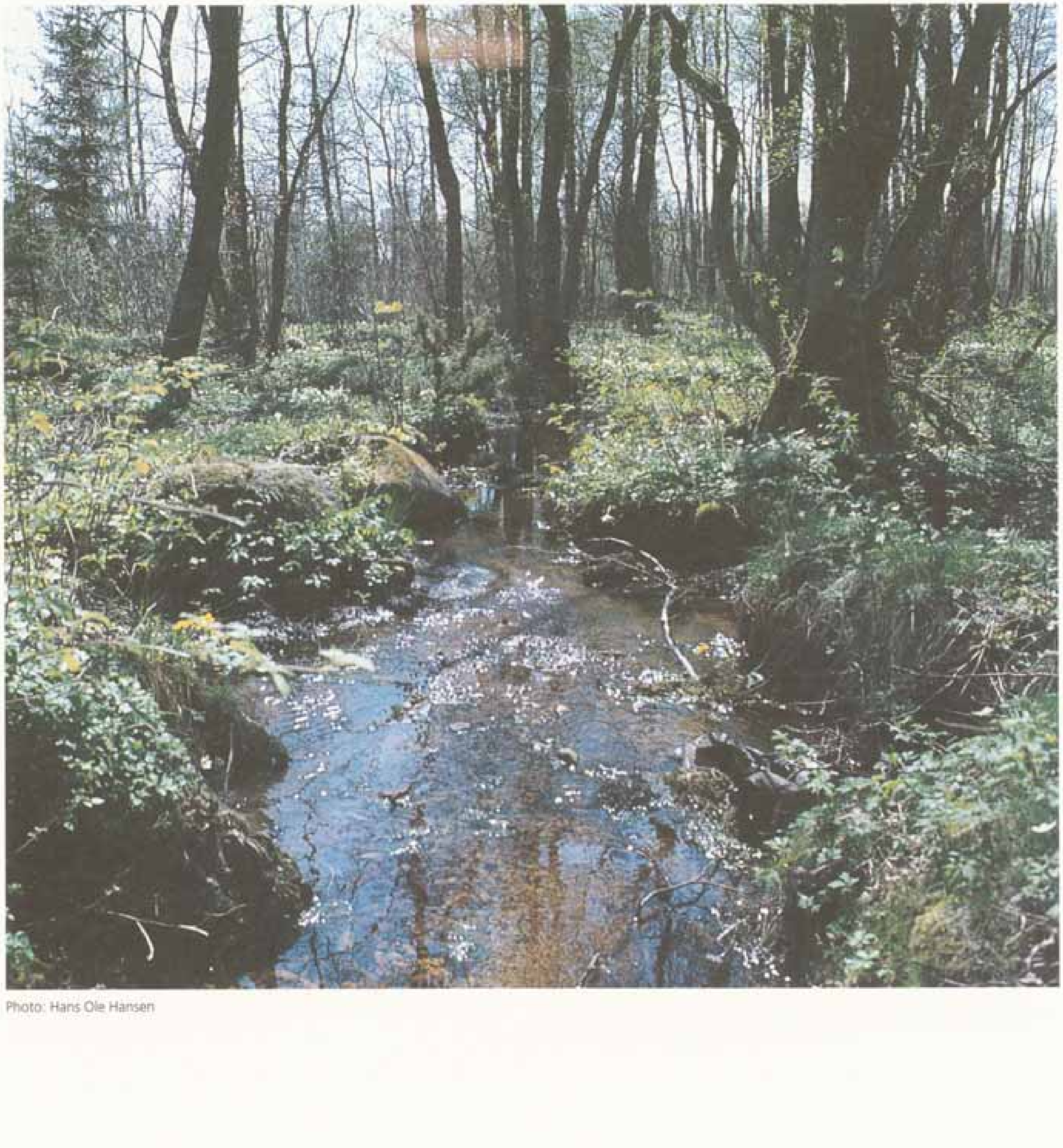
Table of contents



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Preface

This report is one of the first to attempt an all-European assessment of the environmental state and trends of inland surface waters. It provides a general overview which may be used as a basis for implementing general measures to improve water quality and physical conditions of rivers and lakes and to identify areas with environmental problems.

The report appears as the first in a series of monographs to be published by the European Environment Agency on thematic, sectorial or problem areas. These monographs are also aimed at developing "building blocks" for the Agency in its preparation of an integrated report on the state of the environment every three years.

The present report has been prepared by the National Environmental Research Institute (NERI) of the Danish Ministry of Environment and acts as a background document to the report "Europe's Environment – The Dobříš Assessment". This all-European state of the environment report was asked for by the European environment ministers at a meeting at Dobříš Castle in former Czechoslovakia in June 1991 and was prepared by the European Environment Agency Task Force of the European Commission DG XI, in cooperation with the UNECE and other international organisation. To carry out the assessment of the quality of European rivers and lakes NERI was given financial assistance from the European Commission's PHARE service especially to collate environmental information from Central and Eastern European countries. Additional financial support was provided by the Danish Environmental Protection Agency and the Danish National Forest and Nature Agency.

Opinions and views expressed in the present report are the responsibility of NERI and they do not necessarily reflect those of the European Commission or the European Environment Agency.

Domingo Jimenez-Beltran
Executive Director

Acknowledgements

The report has been prepared and edited by Peter Kristensen and Hans Ole Hansen, both employed at the National Environmental Research Institute (NERI), Department of Freshwater Ecology.

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Their contributions are greatly acknowledged.

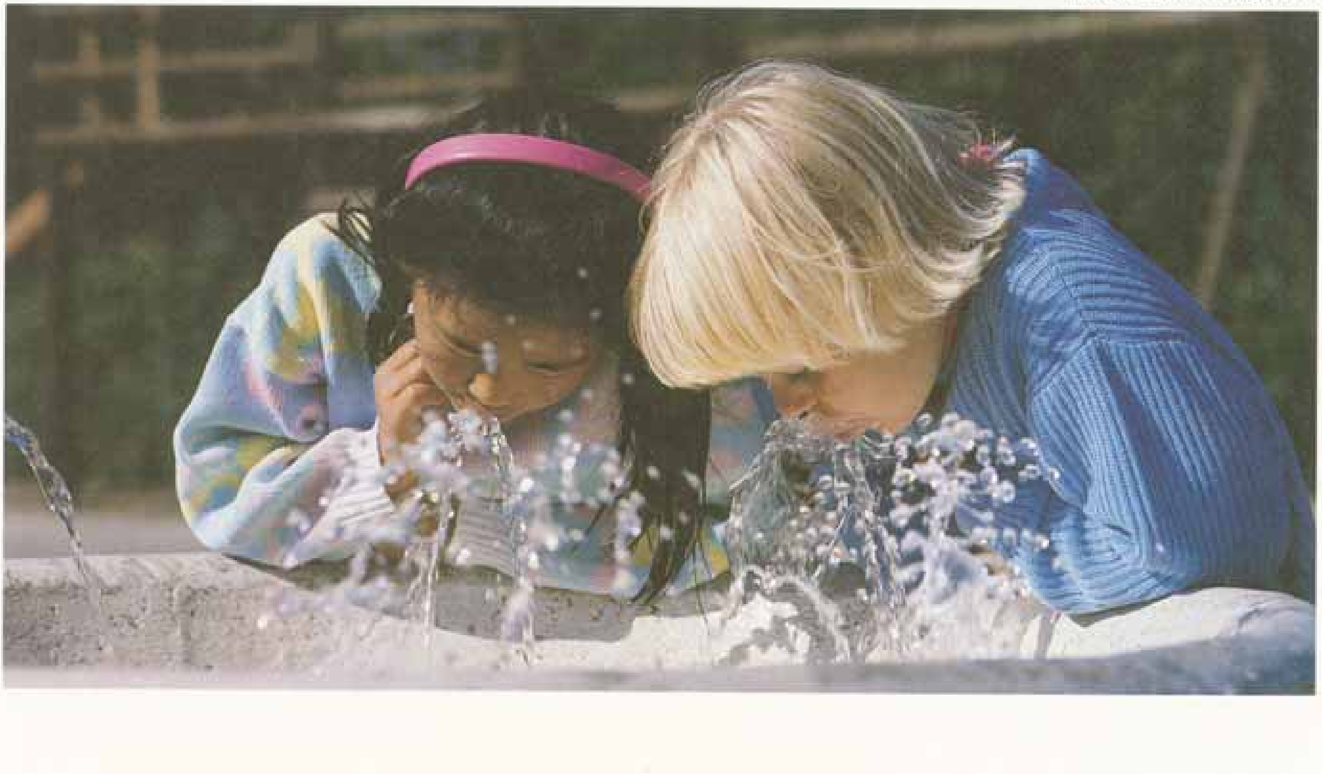
Furthermore, many persons in many countries (see Appendix) have made a great effort to answer the questionnaires; they too are gratefully acknowledged.

We are also grateful to Niels Thyssen, EEATF; Oluf Christiani, National Forest and Nature Agency; Mogens Erlandsen, NERI; Torben Moth Iversen, NERI; Erik Jeppesen, NERI; and Jørn Kirkegaard, Danish Environmental Protection Agency for their ideas and advice throughout the preparation of the report.

In addition, the assistance of David Barry (linguistic review), Kathe Møgelvang and Juana Jacobsen (layout), and Anne Mette Poulsen and Pia Nygaard Christensen (manuscript preparation and proof-reading) is also highly appreciated.

The report has been financially supported by the Danish Environmental Protection Agency and the National Forest and Nature Agency within the Danish Ministry of Environment and Energy.

Photo: L. Havn Eriksen/BIOFOTO



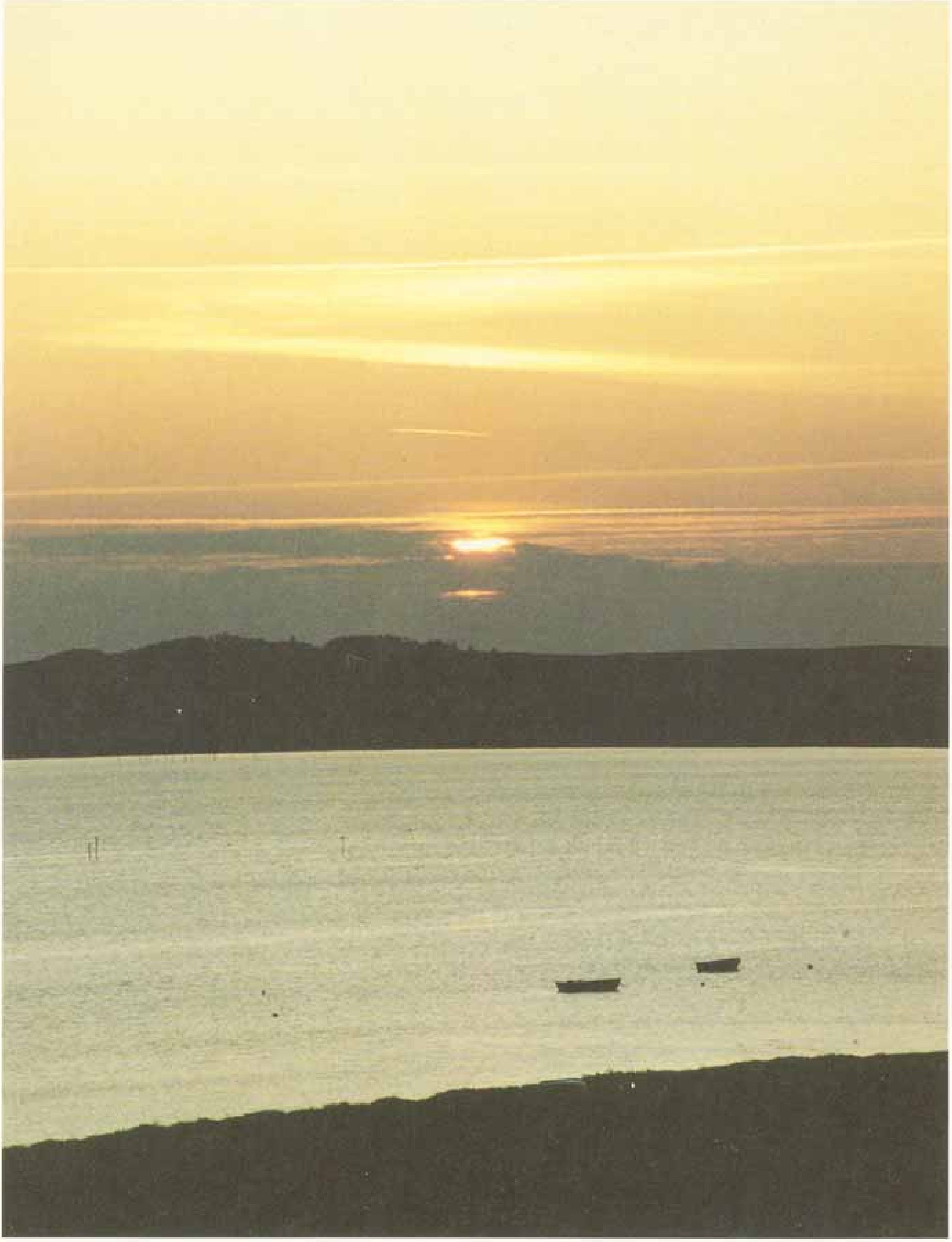


Photo: Martin Søndergård

Extended summary

Introduction

This report focuses on European inland surface waters, ie. rivers, lakes, and reservoirs, and reviews their environmental state and the environmental problems caused by human activity.

At present, European inland surface waters are mainly used for public water supply, waste disposal, irrigation, industrial processes and cooling, transportation, and hydroelectric power generation. However, their use for recreational purposes such as bathing, sailing, sports fishing and simple enjoyment is becoming increasingly important. The growing number of both uses and users has increased the exploitative pressure on European freshwater resources, and hence increased the conflicts between various uses and users, as well as between man and the organisms that live in or near such waters. The use of rivers and lakes for waste disposal from municipalities, industries, or mining activities is in clear conflict with their use for public water supply, crop irrigation and livestock watering since the latter uses require high water quality. The use of inland surface waters for waste disposal also dramatically affects organisms living in the water, and may even eliminate or favour certain species. Their use for recreational purposes may also be affected, for example by toxic substances and frequent algal blooms that arise when nutrient levels are high as a result of waste water discharge and agricultural runoff.

European rivers

In proportion to its land area, Europe has the longest coastline of all continents. As it is a relatively young and structured continent from the geological point of view, river catchments are numerous but relatively small and rivers are short. The three largest European rivers, the *Volga*, the *Danube*, and the *Dnepr*, drain one quarter of the continent, but are small by world standards, their catchments ranking 14th, 29th, and 48th, respectively. The 31 largest rivers in Europe, all of which have catchment exceeding 50 000 km^2, drain approximately two thirds of the continent. More than half of these rivers have their catchment in the former *Soviet Union*, while another ten of these large rivers drain into the Atlantic and the North Sea.

European lakes

Many natural European lakes appeared 10-15 000 years ago, during the last glacial period. The ice sheet covered all of northern Europe, but in central and southern Europe it was restricted to the mountain ranges. As a rule, the regions that have many natural lakes are those that were affected by the ice sheet. Thus, *Norway, Sweden, Finland* and the *Karelo-Kola* part of the *Russian Federation* have numerous lakes, while most natural lakes in central Europe lie in mountain regions, those at high altitude being relatively small, and those in the valleys being the largest. Countries that were little affected by the glacial period have few natural lakes - for example, great parts of the central European lowlands. In these areas, man-made lakes such as reservoirs and ponds are often more frequent than natural lakes.

In Europe there are more than 500 000 lakes larger than 0.01 km^2, of which about 80-90 per cent are small with a surface area between 0.01 and 0.1 km^2, and only about 16 000 have a surface area exceeding 1 km^2. Lake *Ladoga* and *Onega* located in the northwestern part of the *Russian Federation* are the largest European lakes. Both are considerably larger than other European lakes and reservoirs, but nevertheless rank only 18th and 22nd in world order. The third largest European freshwater body is the *Kuybyshevskoye* reservoir on the *Volga*.

Information sources

Considerable environmental information on rivers and lakes is currently collected and reported by various regional or national authorities. However, this information is heterogenous, and therefore difficult to collate as a pan-European environmental report. Nevertheless, a first attempt at doing so has been made in this report. The primary focus is on frequently measured water quality parameters (eg. organic matter in rivers, nutrients in rivers and lakes, and acidification of inland surface waters) since the wide geographical coverage makes these variables well-suited to illustrate the general environmental state of European inland surface waters. The state of and the threats to European flora and fauna in relation to inland surface waters are illustrated by short descriptions of a number of species. Various sources were used in the compilation of the report, including the scientific literature, questionnaires submitted to each country's focal point, and national or regional reports on the environmental state of inland surface waters. The various environmental factors and their effects on water use are described below.

River regulation

River regulation is a general term that describes the physical changes man imposes on watercourses, the most important of which are the construction of reservoirs, channelization, land drainage, and irrigation. Many European rivers have now been regulated, and in some countries few unregulated rivers remain. The extent of regulation is greatest in western and southern Europe, although many river systems in eastern Europe and Nordic countries have been affected by the construction of reservoirs. There are now more than 4000 large reservoirs with dams higher than 15 m in Europe, half of which have been built since 1961; in addition, there are several thousand smaller reservoirs spread across the continent. Reservoirs markedly affect the natural flow regime, as well as the transport of suspended matter. The ecological consequences can be manifold, one example being the obstruction of faunal migration and a reduction in biological diversity in and downstream of the dam. Reservoir construction in Europe has fallen off during recent years, mainly because of lack of suitable sites. Nevertheless, the impact of the existing reservoirs will continue to affect the environmental state of many rivers, and one of the important environmental issues of the future will be to protect the few remaining unregulated large river systems. Another issue of concern is that many reservoirs are located in transboundary rivers and can therefore give rise to international conflicts concerning water rights and quality (eg. the Gabcikova hydroelectric power plant on the *Danube*).

Organic pollution

The many areas of Europe with high population density and high industrial development pose a potential threat of pollution because of the high production of organic waste, organic pollution being known to lower the oxygen level of the receiving water body. The detrimental effect of this is most marked in rivers, where it mainly affects aquatic organisms requiring high oxygen levels; in the case of severe organic pollution, river habitats become uniform since only a few robust species are able to tolerate the low oxygen concentration.

At present, European rivers are generally fairly well oxygenated and able to support a healthy aquatic biota. Organic matter levels in rivers are generally low in the sparsely populated areas (eg. the Nordic countries and the Alpine region), while the heavily affected rivers are mainly located in a band across central Europe, particularly in *Belgian Flanders, Bulgaria, the Czech Republic, Moldova, Poland, Rumania*, and *Spain*.

The level of organic matter in many European rivers has decreased over the last 15 years. Thus, a comparison of data from 223 European rivers for the periods 1977-82 and 1988-90 showed a decrease in organic matter concentration in almost 75 per cent of the rivers while the reduction was greater than 25 per cent in 41 per cent of the rivers, there was an increase of more than 25 per cent in 8 per cent of the rivers. The improvement was greatest in western Europe, and less pronounced in eastern Europe, where about 40 per cent of the rivers had increasing organic matter concentrations. Although many European countries have developed action plans to reduce the organic load by ensuring that waste water is collected and adequately treated, the economic recession and the general economic situation have slowed the construction of sewage treatment plants. It is therefore still necessary to focus on rivers in which organic loading is high so as to ensure the implementation of effective measures to reduce organic loading.

Eutrophication

Eutrophication is the excessive enrichment of a surface water body with nutrients. This stimulates the growth of aquatic plants, especially phytoplankton, thereby causing the water to become turbid. Eutrophication may provoke a shift in the biological structure of the water body, and cause excessive growth of potentially poisonous blue-green algae. In cases where the surface water is used for domestic water supply, this necessitates that the water be treated and filtered prior to use. The effects of eutrophicaion are generally most apparent in lakes, reservoirs and coastal areas, as well as in large slowly flowing rivers.

Eutrophication of surface waters is a widespread problem in Europe. In general, nutrient levels are lowest in the rivers of the sparsely populated Nordic countries, and highest in the countries situated in a band stretching from the southern part of *the United Kingdom* to the Balkan area and *the Ukraine*. There is a close relationship between phosphorus concentrations and catchment population density, and between nitrogen concentration levels and the percentage of the catchment used for agricultural purposes. Most of the phosphorus loading of inland surface waters is attributable to discharge from point sources, especially municipal sewage water and industrial effluent, while nitrogen loading is primarily derived from agriculture activity, especially from the use of nitrogen fertilizers and manure.

The European lakes with the lowest phosphorus concentrations are found in *Norway, Sweden* and *Finland*, lake total phosphorus level being below 25 $\mu g\ P\ l^{-1}$ in 75-90 per cent of the lakes. The lakes in the Alpine region also have relatively low phosphorus levels, the majority of lakes having concentrations below 25 $\mu g\ P\ l^{-1}$. In central Europe, lake phosphorus levels are generally high, in *Spain, England*, and *Wales, Rumania, Denmark, Poland, The Netherlands* and *Moldova*, for example, phosphorus concentrations exceed 50 and 125 $\mu g\ P\ l^{-1}$ in more than 80 per cent and 45 per cent of the lakes, respectively. The level of total nitrogen in lakes shows the same tendency as for phosphorus. Thus, the majority of lakes in the sparsely populated Nordic countries have low nitrogen levels, while the lakes in central Europe have high concentrations; in *Denmark* and *Poland*, for instance, 85-90 per cent of the lakes have total nitrogen levels higher than 0.75 $mg\ N\ l^{-1}$. As a consequence of the high nutrient level many of the lakes have high phytoplankton concentrations, and hence very turbid water.

Improved waste water treatment has led to a decrease in the phosphorus concentration of most European rivers and many lakes over the last 10-15 years. Data from 221 European rivers shows that the phosphorus concentration in the majority of the rivers (64 per cent) decreased between the period 1977-82 to 1988-90. In one third of the rivers, the reduction was greater than 25 per cent. The reduction in phosphorus levels was most marked in western Europe, a reduction of more than 25 per cent being observed in half of the rivers. A similar reduction in phosphorus loading and concentration has been observed in several European lakes. However, in many lakes the concentration is still high, and little improvement has been observed in water quality.

The ammonium level in many European rivers has also declined, this being mainly attributable to improved waste water treatment and increased awareness of the importance of correct handling and storage of manure and silage. The improvement has been most marked in the western European rivers, while the ammonium levels have increased in several rivers in eastern Europe.

In contrast to phosphorus and ammonium levels, the nitrate level in most European rivers has increased during the last 10-15 years, mainly as a result of the increasing use of nitrogen fertilizers. Thus, nitrate levels increased between 1977-82 and 1988-90 in more than two thirds of 230 European rivers.

Nevertheless, nutrient levels are still far too high in many areas of Europe, and unless drastic efforts are made to reduce nutrient input, eutrophication will continue to be an important European environmental issue. It may prove necessary to require phosphate precipitation in waste water treatment plants or a reduction in the phosphorus content of detergents, as well as measures to reduce nitrogen and phosphorus run-off from agricultural areas. Successful restoration of eutrophic lakes is possible, but expensive, and the recovery time can be long. However, recovery may be shortened by additional measures to reduce phosphorus release from the sediment or to overcome biological resilience.

Acidification

Acidification of surface water is found in areas where acidic deposition is high and the catchment soil and bedrock is poor in limestone and other easily weatherable minerals. During the last century, acidic deposition in Europe has increased markedly as a consequence of increased atmospheric emission of sulphur and nitrogen oxides, in particular from the burning of fossil fuels. The southern parts of *Finland*, *Sweden*, and *Norway* are the areas most seriously affected by surface water acidification, but lake acidification has also been recorded in the *Karelia* and in the *Kola Peninsula* in the *Russian Federation*. Most surface waters in western and central Europe are not affected by acidification. However, acidification has been observed in a number of areas, including high altitude lakes in some mountain regions, lakes and rivers in some forest areas of central Europe, surface waters in acidic soil areas of *Scotland*, northern *England*, and *Wales*, and small seepage lakes in northwestern Europe.

Acidification affects aquatic ecosystems at all levels and has a profound impact on both plant and animal communities. Aquatic organisms are influenced both directly, because of the resulting toxic conditions, and indirectly because of the loss of suitable, acid sensitive prey. Waters with a pH below 5.0 are generally devoid of fish. In southern *Norway*, for example, 1750 of 5000 lakes are completely devoid of fish as a result of acidification, while a further 900 lakes are seriously affected. The Atlantic salmon is now virtually extinct in 25 rivers in southern *Norway* due to acidification.

A reduction in acidifying emissions of sulphur and nitrogen oxides is generally considered to be the only effective long-term solution to the problem of freshwater acidification. The majority of European countries are committed to reducing the emission of both sulphur and nitrogen oxides. In Helsingfors in 1985, 21 European countries signed a convention aimed at reducing national sulphur dioxide emissions to approximately 70 per cent of the 1980 level by 1993. Similar agreements for reducing nitrogen oxide emissions were made by 12 countries in Sofia 1988, while most other countries only agreed to freeze nitrogen oxide emissions at the 1987 level until 1994. At present, little is being done to control ammonia emissions. From 1980 to 1990 sulphur emissions in Europe have been reduced by 27 per cent. The reductions achieved are greatest in western Europe (48 per cent), and proportionately less in eastern Europe (18 per cent). Emissions of nitrogen oxides have risen by 5 per cent in the same period, while emissions of ammonium have remained more or less unchanged. However, since the required reduction in acidifying emission is estimated to be as much as 70-80 per cent, and as only a few countries have implemented plans for a reduction of that magnitude, considerable investment will be needed if the deterioration of European lakes and rivers by acidification is to be stopped.

Some countries have used liming of inland surface waters to counter the adverse effects of acid deposition. Thus more than 6000 water bodies have been limed since the 1970s in *Sweden*, 1200 in *Norway*, and hundreds in *Finland*. Liming has only a short-term effect, however, and two to three years after a lake has been limed, the majority of the lime will either have been used or washed out of the lake.

Heavy metals

The production and use of heavy metals has increased markedly in Europe during the 19th and 20th centuries. As a result, heavy metal contamination of inland surface waters has also increased, the main sources being mining and industrial activities. The increase in acidic deposition has also led to increased mobilization of metals from the soil, and hence to elevated heavy metal levels in the aquatic environment.

The level of heavy metal pollution of European rivers and lakes is difficult to compare and assess, primarily because the measurement of heavy metals is rarely included in monitoring programmes, but also because concentration levels are usually so low that problems arise with sample preparation and methodological precision. In general, the heavy metal concentrations in European rivers are well below standards for drinking water. However, human activity has led to increased levels of heavy metals in several rivers, and in some, particularly those located near mining areas or industries using large quantities of metals, high metal levels have been recorded. Although the adverse influence of heavy metals on the aquatic biota in Europe is generally overshadowed by other environmental problems, especially eutrophication and acidification, its negative impact on the aquatic biota cannot be ruled out.

In the 1970s metal concentrations reached alarming levels and regulations were therefore implemented to control heavy metal release at the source. This has reduced levels of harmful metals in many western European rivers during the last decade, but the positive reduction in the direct input of heavy metals into aquatic systems has partly been offset by other negative factors such as increased mobility of toxic metals as a consequence of the increased acid precipitation. Moreover, the introduction of chelating agents to replace polyphosphates in detergents may interfere with natural removal processes and may remobilize metals from particulate matter, while the draining of marshes and wetlands may reduce the number of sinks available for mobilized metals.

Organic micropollutants

The marked increase in the use of pesticides during the last 30 years and the increased production of synthetic organic substances used in various industries have led to pollution of inland surface waters by a wide variety of organic micropollutants. While the toxic effects of some organic micropollutants are well known (eg. DDT, PCBs), and others are suspected of having various adverse effects, the environmental impact of many others remains to be elucidated. The threat from organic micropollutants is enhanced each year by the production and potential for release into the aquatic environment of a vast number of new organic chemicals.

The effect of organic micropollutants on the aquatic environment is very difficult to analyze. Information on organic micropollutants in European inland surface waters is currently insufficient to document the extent and seriousness of the problem. However, it is a well-known fact that the many heavily agricultural and industrialized areas of Europe potentially constitute a major threat of pollution. Of major concern therefore is either to ban or restrict the use of toxic or potentially toxic micropollutants, and to ensure that the handling and use of these and other organic substances does not result in their discharge into the aquatic environment.

Radioactivity

Various human activities such as nuclear power production and nuclear waste disposal have increased the potential for contaminating the aquatic environment with radionuclides.

Nuclear power plants are built close to a major water source, either inland or coastal, and this may result in reduced flow and thermal pollution. In addition, the passage of water through the power plant may lead to its contamination with radionuclides. More than 200 nuclear power plants are currently in operation in Europe. Although elevated radiation levels are observed downstream of these plants, the levels observed are generally well below those considered of any significance from the point of view of human health. However, the risk of accidents cannot be ruled out (eg. Chernobyl). Nuclear waste disposal sites are another potential source of contamination of inland surface waters. There have been several reports from eastern European countries of the careless handling of radioactive waste having led to or being a potential source of contamination of rivers and lakes.

Other hazards

Many other human activities affect the environmental state and water quality of inland surface waters, eg. thermal pollution, transportation and navigation, water abstraction for irrigation and human consumption, discharge of pathogens, and salinization. The environmental problems associated with these activities are either not described or are only briefly mentioned in the present report, although these problems may be of major importance locally.

The biology of European inland surface waters

River, lake, and wetland ecosystems are an important part of European nature. The physical characteristics of a river (eg. current, gradient, temperature) continuously change as the river progresses from its source to its mouth. The chemical characteristics of river water also vary from reach to reach, reflecting both local and upstream conditions. Thus a river system is a continuum of habitats that varies according to local physical and chemical conditions, and one that is able to support an impressive array of biological communities along its course. The most distinctive characteristic of lakes is that the water is standing. Lake ecology varies depending on whether the lake is deep or shallow, large or small. Lakes typically have several biological communities in their constituent parts, eg. submerged macrophytes in shallow water and phytoplankton at greater water depths. Flood plains and wetlands alongside rivers and lakes are highly productive ecosystems;

they provide important feeding and breeding areas for fish, insects, and birds, and serve as pollution sinks that reduce the pollution of the aquatic environment. The presence of characteristic plants, fish, birds, and mammals in or along rivers and lakes is an integral part of the experience these natural environments offer, not least because many of the animals are of importance to recreational fishing and hunting.

About 250 species of macrophytes and 250 species of fish inhabit European inland surface waters, and about 25 per cent of all European birds and 11 per cent of all European mammals depend on freshwater wetlands for breeding or feeding.

Deterioration of water quality, channelization, loss of wetlands, etc., have detrimentally affected many European freshwater habitats and resulted in the loss of their natural vegetation and animal life. Not only has the existence of many species become rare, vulnerable or threatened, but some have even become extinct in parts of their natural distribution area.

On a global scale the loss of animal and plant species is occurring at a rate faster than ever previously recorded. Twenty species of fish, nine species of birds and five species of mammals from European freshwater habitats are included in the IUCN Red List of Globally Threatened Species, with many more species being included in several of the national European red lists. This reflects the fact that more species are endangered on a regional level, and their populations may have vanished or been relegated to areas so small that their future survival is uncertain. New and ongoing investigations are needed in order to provide a realistic picture of distribution and habitats, animal and plant species, and thereby enable their classification on the national and international red lists.

Aquatic macrophytes

Many European surface waters have lost their natural aquatic vegetation in recent years, submerged macrophytes having been particularly affected by the deterioration of water and habitat quality. As submerged macrophytes only occur in the aquatic environment, they are very sensitive to changes in water and habitat quality. Each species is more or less adapted to a specific type of aquatic habitat with its special water and the sediment characteristics. One feature common to all submerged macrophytes is their dependence on sufficient light; any decrease in light transmission caused by an increase in water turbidity will therefore lead to a reduction in vegetation density and a decrease in the maximum depth at which plants can grow. In extreme cases, such as in many very turbid European lakes and rivers, all submerged macrophytes disappear completely. Since submerged macrophytes are of major importance to lake and river biological and chemical processes, their disappearance has changed the ecosystem and the ecological stability of many lakes and rivers.

Fish

European freshwater fish populations are affected by many types of environmental deterioration. In many rivers, organic pollution and the resulting oxygen depletion and high concentration of ammonia has significantly reduced fish populations, as has the discharge of oxygen consuming organic substances. Acidification can severely affect the fish fauna of lakes and rivers. In addition, channelization, maintenance activities, and increased sediment transport have destroyed spawning grounds and nursery areas. Similarly, the establishment of dams and weirs has reduced the access of migratory fish to large areas of potential spawning grounds and has fragmented the population of many species. Overfishing is a major problem in connection with many commercially interesting species. Moreover, eutrophication of many inland surface waters has changed the fish community, with species more tolerant to the turbid environment having become dominant.

The future

Increasing appreciation of the need to act against the above mentioned threats to the European freshwater environment provides hope that the overall decline in freshwater life will soon cease. Ensuring an optimal freshwater floral and faunal diversity throughout Europe necessitates improving water quality in combination with conservation programmes and the proper management of the plants and animals and their habitats. This will require international cooperation and large-scale investment to reduce pollution discharge and re-establish habitats, as well as the regulation of the various uses to which inland waters are put.

Sustainable use and development

Although still of good quality in some regions, European inland surface waters are threatened by a multitude of human activities. The result can be a decline in the quantity and quality of water available for human uses, as well as of the ecological quality of water bodies. In view of these problems, better integrated water management is urgently needed to halt and reverse the deterioration of their environmental quality. One of the basic concepts for water quality management is that both water quality and availability must be integrated in both long-term planning and in policy implementation. Moreover, water quality should be a central element in the inception and development of plans and policy. This has led to a concept of sustainable use and development that emphasizes the finite nature of water resources and their limited assimilative capacity for pollutants. Development plans should bear this in mind. It is important that quantity and quality are seen to be linked since high abstraction from a water body will reduce its capacity to dilute and assimilate effluents without them having adverse effects. The practical consequence is that more emphasis should be placed on the ecological basis for water quality analysis and management, and for the planning for water use.

Reliable high quality information about the environmental quality of inland surface waters is essential for water management and the implementation of optimal measures to improve environmental quality. Greater knowledge of water quality at the regional and European levels is needed if the management of inland waters at the European level is to be improved. This report is one of the first attempts to assess the environmental state of European inland surface waters, the overview would be significantly improved if more information were to be included, however. The final chapter of the report therefore discusses how the considerable information on rivers and lakes currently collected and reported by various large regional and national authorities may be collated in an all-European environmental report. Such a report would be invaluable for 1) assessing the general environmental state of inland surface waters, 2) identifying areas with severe environmental problems, 3) providing a basis with which to identify and assess environmental threats at the regional and global levels, 4) providing information necessary to ensure that society develops in an environmentally sustainable way, and 5) enabling general actions to be taken to improve the environmental state of inland surface waters.

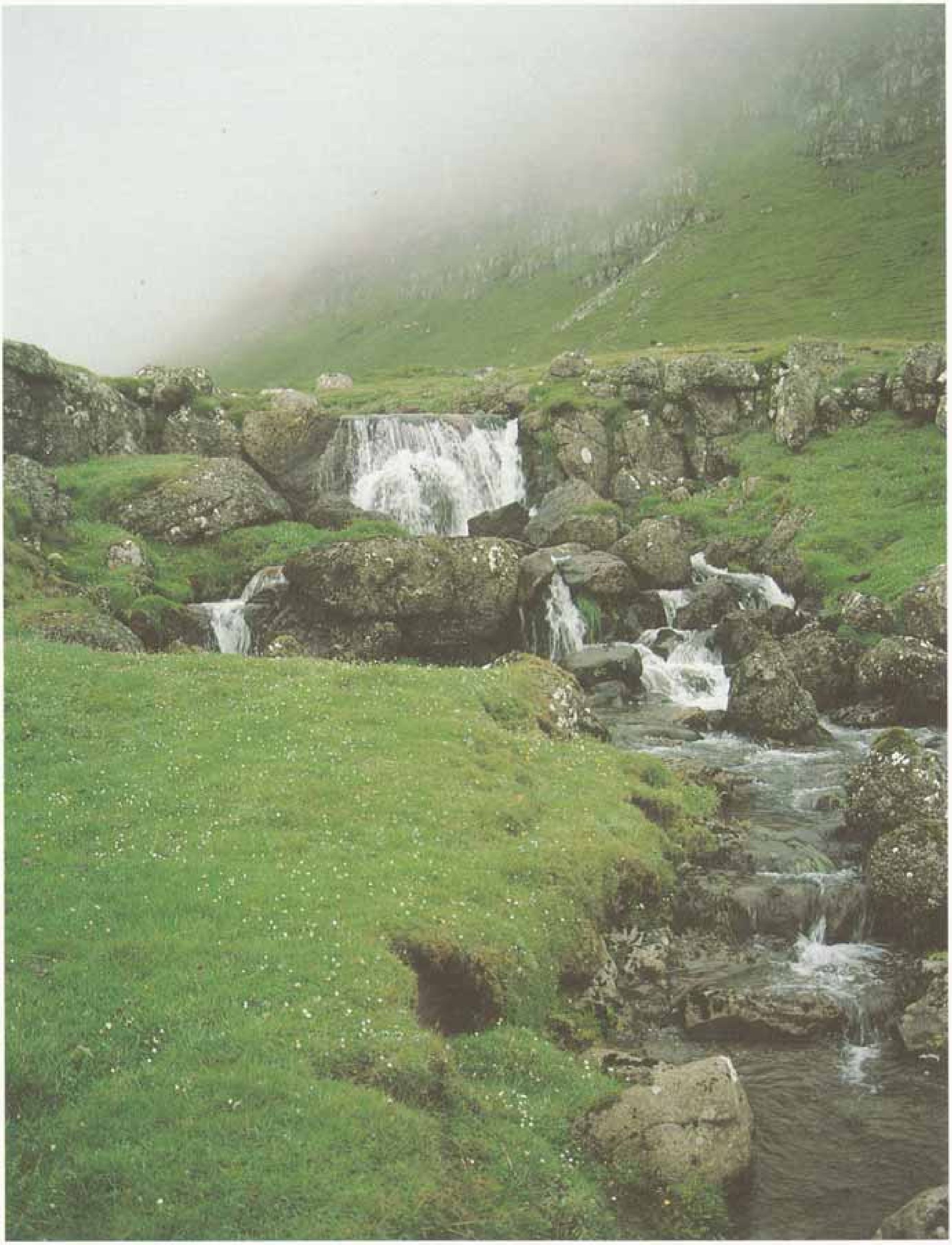


Photo: Hans Ole Hansen

1 Introduction, data, and information sources

Life on earth originated in water and water in sufficient quantity and of sufficient quality is necessary for the well-being of all living organisms. Furthermore, the evolution of mankind and human civilization has been closely linked to aquatic media, especially to fresh water. The importance and intensive use of fresh water therefore makes it a vulnerable and increasingly limited resource, especially since fresh water is usually reclaimed from groundwater and inland surface water, the two aquatic media that are most affected by human activities. This report focuses on European inland surface waters, ie. rivers, lakes, and reservoirs, and reviews their environmental state and the environmental problems caused by human activity.

Usage of European inland surface waters

Man has probably always used inland surface waters as a source of drinking water and food (eg. fish and molluscs) and for transportation. As agriculture developed, fresh water was also used to irrigate crops and to run corn and saw mills, etc. This led to the first physical changes in watercourses: dams and reservoirs were built, and lowlands were drained. As large urban settlements developed, the need for waste removal increased and sewers were therefore constructed, the waste being discharged directly into nearby rivers or lakes in the belief that the waste products would thereby be diluted, exported, and decomposed. Industrial development increased the number of ways surface waters are used, for example for electricity production and cooling purposes.

Inland surface waters are still used for these purposes, but the magnitude of use has in many cases changed, for example from small mill dams to very large reservoirs. In addition, the importance of some uses of inland surface waters has diminished, for example for food supply. At present European inland surface waters are mainly used for public water supply, waste disposal, irrigation, industrial processes and cooling, transportation, and hydroelectric power generation. However, their use for recreational purposes such as bathing, sailing, sports fishing and simple enjoyment is becoming increasingly important.

While the various uses that are made of surface waters require that the rivers and lakes have a certain quality, many of the uses deteriorate water quality, thereby affecting its use for other purposes. The growing number of both uses and users has increased the exploitative pressure on European freshwater resources, and hence increased the conflicts between various uses and users, as well as between man and the organisms that live in or near such waters.

The use of rivers and lakes for waste disposal from municipalities, industries, or mining activities is in clear conflict with their use for public water supply, crop irrigation and livestock watering since the latter uses require high water quality. The use of rivers and lakes for waste disposal also affects their biological structure, and may even eliminate or favour certain species. Their use for recreational purposes such as bathing may also be affected, for example by toxic substances and the frequent algal blooms that arise when nutrient levels are high as a result of waste water discharge and agricultural runoff. Other uses, such as transportation and hydroelectric power generation, are independent of water quality but require water in large amounts; for this reason it is often necessary to construct dams, reservoirs, sluices, and bank stabilizing structures. These may affect aquatic organisms, for example, by hindering the up- and downstream migration of migratory fish, or by changing water flow and temperature regimes such that the entire aquatic ecosystem is disturbed.

Although the various ways in which inland surface waters are used can be justified to some extent, for example because hydroelectric power stations produce electricity without the burning of fossil fuel, waste water discharge removes our waste products, and irrigation increases crop yield, each use affects the use of the water for other purposes.

Assessment of the environmental state of European inland surface waters

The European continent covers about 10 million km², stretching from the Atlantic Ocean and Iceland in the west to the Ural Mountains and the Caspian Sea in the east, and from the Barents Sea in the north to the Mediterranean and the Black Seas in the south (*Figure 1*); there are several million km of flowing waters and more than a million lakes, each with their own characteristics and, perhaps, environmental problems.

This report is one of the first to attempt an all-European assessment of the environmental state of inland surface waters. It aims at providing a general overview for use as a basis for implementing general measures to improve the environmental state of rivers and lakes, and to identify areas with environmental problems.

Considerable environmental information on rivers and lakes is currently collected and reported by various regional or national authorities. However, this information is very heterogenous, and therefore difficult to collate on a pan-European basis as a European report. Nevertheless, a first attempt at doing so has been made in this report. The primary focus is on frequently measured water quality parameters (eg. organic matter in rivers, nutrients in rivers and lakes, and acidification of rivers and lakes) since the wide geographical coverage makes these variables well-suited to illustrate the general environmental state of European inland surface waters. Some environmental problems related to more rarely

Figure 1: Map of Europe.

monitored parameters are also described, and the state of and threats to European flora and fauna in relation to inland surface waters are illustrated by short descriptions of a number of species.

This report concerning European rivers and lakes has been prepared by the National Environmental Research Institute (NERI) of the Danish Ministry of Environment and Energy. In 1992 NERI formally agreed to prepare the inland surface water section of the report "Europe's Environment – The Dobříš Assessment" (1994). The latter, which was prepared by the European Environment Agency Task Force (EEA-TF), was called for by the European environmental ministers at a meeting at Dobříš Castle in June 1991. NERI was given financial assistance by the PHARE service of the Commission of European Communities (CEC) especially to collate environmental information from eastern and central European countries. Questionnaires about inland fresh surface waters jointly prepared by the EEA-TF and NERI were forwarded to all European countries; NERI has been responsible for collating, evaluating, and reporting the information. Parts of chapters 2 and 3 in the present report are also incorporated in the report "Europe's Environment – The Dobříš Assessment" (1994), while chapters 4, and 5 are extensions prepared only for the present report.

Sources of data and information

The data and information in this report is based on:

- questionnaires forwarded to national focal points in each European country,
- various national and regional state of the environment reports, and
- a review of the scientific literature concerning the environmental state of European rivers and lakes.

Four different questionnaires were used. Two were designed to provide general information about the rivers and lakes in each country, while the other two were designed to provide more specific information about 10-20 rivers and lakes in each country. In addition, time-series data for rivers was obtained from the CEC (Council Decision (77/795/EEC) on Exchange of Surface Water Quality), the UNEP/GEMS database in Burlington, Canada, and from a supplementary questionnaire sent to countries outside the EC. The questionnaires were used as a tool to ensure that comparable information was obtained on the various environmental problems in the different countries. Many persons in many countries have made a great effort to answer the questionnaires; they are greatfully acknowledged. The *Appendix* lists the organizations and persons who have contributed. A total of 28 countries, especially central and eastern European, and EFTA countries, were kind enough to answer the questionnaires (*Table 1*). However, the information supplied differed greatly; some countries only provided sparse information about a few water bodies, while others supplied information from national surveys that included 500-1000 rivers or lakes. When a response to the questionnaires was lacking or incomplete, national or regional environmental reports were reviewed and analyzed so as to ensure as wide a geographical coverage as possible.

Table 1:

Countries that have answered the river and lake questionnaires. Questionnaire I is general, and questionnaire II gives informations about specific rivers and lakes. The number of rivers and lakes for which information was provided is given.
( ): only sparse information provided.

Country	Rivers		Lakes	
	Q I	Q II	Q I	Q II
Albania	+	5	-	(3)
Austria	(+)	4	(+)	-
Bulgaria	+	10	(+)	5
Croatia	+	26	-	4
Czech Republic	+	15	-	-
Denmark	+	70	+	37
Estonia	-	12	+	3
Finland	+	21	+	19
France	+	-	-	-
Georgia	+	14	(+)	6
Hungary	+	4	-	3
Iceland	+	2	+	1
Latvia	+	15	+	-
Lithuania	+	15	-	-
Luxembourg	+	-	+	-
Moldova	+	7	+	9
Netherlands	+	3	+	7
Norway	+	19	(+)	12
Poland	+	19	+	16
Romania	+	26	-	16
Russian Federation	+	16	-	4
Slovenia	+	21	-	-
Spain	+	3	(+)	7
Sweden	+	21	+	9
Switzerland	+	4	+	9
Turkey	-	-	+	-
Ukraine	-	37	-	6
United Kingdom	+	-	+	-

Major additional sources of information were as follows: *Austria*: Wasserwirtschaftkataster, 1992; *the Belgian Flanders*: Vlaamse Milieumaatschappij, 1992; *Estonia*: Milius, 1991; *Ireland*: Flanagan & Larkin, 1992; *Italy*: Istituto di Ricerca sulle Acque, 1990 and Gaggino et al. 1987; *Northern Ireland*: Gibson, 1986 and 1988; *Norway*: NIVA, 1990a,b; *Portugal* (river *Douro* and tributaries): DGQA, 1991; *Spain*: Dirección General de Obras Hidráulicas del MOPU, 1989; *the United Kingdom*: Institute of Hydrology & British Geological Survey, 1990, and Department of the Environment (UK), 1992; the former *West Germany*: Umweltbundesamt, 1992. Little or no information was provided by *Belarus, Bosnia-Herzegovina, Greece, the Former Yugoslav Republic Macedonia, the Slovak Republic*, and *Serbia-Montenegro*. The very small European countries are only briefly considered.

In all, information has been collected from 800 river stations in more than 550 European rivers, as well as from more than 1500 lakes. Information was obtained about the largest rivers in nearly all countries, this being supplemented by data from numerous smaller rivers for which land usage and human activity in the catchment area is known. Descriptive statistics for frequently measured physical and chemical parameters in European rivers are given in *Table 2*.

Table 2:
Descriptive statistics for annual mean physical and chemical variables in European rivers.

	Number of river stations	Percentage of river stations with concentrations not exceeding		
		25%	50%	75%
pH	717	7.5	7.8	8.0
Conductivity (mS m^{-1})	-	-	-	-
Total alkalinity (meq l^{-1})	274	1.0	2.5	4.0
Chloride (mg Cl^{-} l^{-1})	442	17.3	26.5	68.3
Organic matter & oxygen level (mg O$_2$ l^{-1})				
Biochemical Oxygen Demand (BOD)	645	1.9	2.8	4.7
Chemical Oxygen Demand (COD)	470	7.8	15.0	25.0
Dissolved Oxygen	620	8.4	9.7	10.7
Nitrogen (mg N l^{-1})				
Ammonium	580	0.1	0.2	0.4
Nitrate	654	0.7	1.8	3.9
Total nitrogen	329	0.8	2.1	4.5
Phosphorus (µg P l^{-1})				
Dissolved orthophosphate	412	45	124	286
Total phosphorus	546	59	170	366
Heavy metal (µg l^{-1})				
Copper	192	1	4	8
Zinc	176	5	10	36

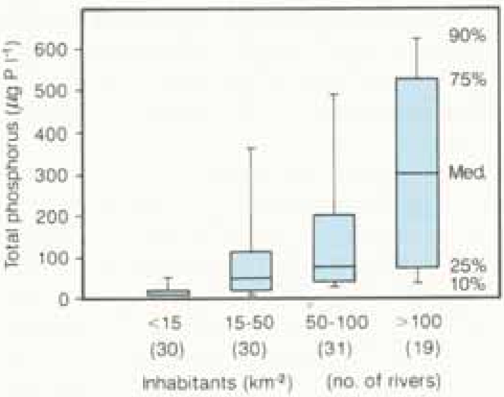


Figure 2:
An example on the use of box-cox diagram showing the relationship between annual mean total phosphorus concentration and population density in river catchments.

Information provided about the general environmental state of European lakes was less extensive, only eighteen countries having completed the general lake questionnaire; this information was therefore supplemented with data from national lake surveys, as well as information from the scientific literature. The various problems encountered in comparing data and information collected in many different monitoring programmes and by several hundred different local authorities are discussed in Chapter 5.

The major sources of information concerning the distribution of aquatic animals and plants were as follows: *plants*: UNECE, 1992, and United Nations, 1991; *fish*: IUCN, 1988, and Holčík et al. 1989; *birds*: Grimmett & Jones, 1989, and Cramp & Simmonds, 1977; *mammals*: Lavsund, 1987.

Presentation of results

The results on chemical concentrations in this report are generally based on annual (rivers) or summer (lakes) mean values from the period 1988-91. Several results are presented as summary statistics for a group of rivers or lakes by means of frequency distributions (pie-charts) and box-cox diagrams. The frequency distribution for organic matter and nutrients in rivers and lakes (maps with pie-charts) are based on information supplied by each country on the percentage of rivers or lakes having organic matter or nutrient levels within specified classes, for example the percentage of rivers with annual mean phosphorus levels below 25 µg P l^{-1}, between 25-50 µg P l^{-1}, 50-125 µg P l^{-1}, etc.

The box-cox diagrams that illustrate, for instance, the relationship between the concentration of total phosphorus in rivers and population density in river catchments (eg. *Figure* 2) have been compiled by grouping the rivers in population density classes, for example 30 rivers with less than 15 inhabitants per km^2 and 19 rivers with more than 100 inhabitants per km^2. The median value (the middle bar), the upper and lower quartiles (the upper and lower box), and the 10 and 90 per cent percentiles (the upper and lower lines) have been calculated for each class. In rivers with a catchment population density exceeding 100 inhabitants per km^2, 50 per cent of the rivers have annual mean total phosphorus levels above and below 300 µg P l^{-1}, and 25 per cent of the rivers have phosphorus levels below 100 µg P l^{-1}.

The European countries dealt with in this report have been divided into four regions: the nordic, the western, the eastern, and the southern regions (*Table 3*).

Table 3:
Countries comprising the four regions widely used in this report.

Nordic countries	Western countries	Eastern countries	Southern countries
Finland	Austria	Belarus	Albania
Iceland	Belgium	Bulgaria	Bosnia-Herzegovina
Norway	Denmark	Czech Republic	Croatia
Sweden	France	Estonia	Former Yugoslav Republic Macedonia
	Germany	Georgia	Greece
	Ireland	Hungary	Italy
	Luxembourg	Latvia	Portugal
	Netherlands	Lithuania	Serbia-Montenegro
	Switzerland	Moldova	Slovenia
	United Kingdom	Poland	Spain
		Romania	
		Russian Federat.	
		Slovak Republic	
		Ukraine	

Photo: Bent Lauge Madsen

2 Characteristics of European rivers, lakes, and reservoirs

A river is a system comprising both the main course and all the tributaries that feed into it, the area that the river system drains being known as the catchment. The main characteristic of rivers is their continuous one-way flow in response to gravity. In addition, because of changes in physical conditions such as slope and bedrock geology, rivers are dynamic and may change nature several times during their course (eg. from a fast flowing mountain stream to a wide, deep, slowly flowing lowland river).

When assessing river characteristics and water quality it is important to bear in mind that a river comprises not only the main course, but also a vast number of tributaries. Thus although the main course of Europe's largest river, the *Volga*, is 3500 km long, it receives water from ten tributaries longer than 500 km, and more than 151 000 tributaries longer than 10 km (Fortunatov, 1979).

Rivers are greatly influenced by the characteristics of the catchment area (*Figure 3*). The climatic conditions pertaining influence the water flow, as does bedrock geology and soil type. The latter also affects the mineral content of the river water. Human activity affects river systems in numerous ways, for example through afforestation or deforestation, urbanization, agricultural development, land drainage, pollutant discharge, and flow regulation (dams, channelization, etc.). The lakes, reservoirs, and wetlands in a river system attenuate the natural fluctuation in discharge and serve as settling tanks for material transported by the rivers. For example, whereas the water of the *Rhine* is very muddy and turbid when entering the *Bodensee*, it is clear and transparent when leaving. Water flow and water quality are therefore the net result of the various characteristics of the catchment.

Lakes are bodies of standing water that is usually fresh, but which may also be brackish. Although lakes may be characterized by physical features of the lake basin, for example lake area and water depth, the character-

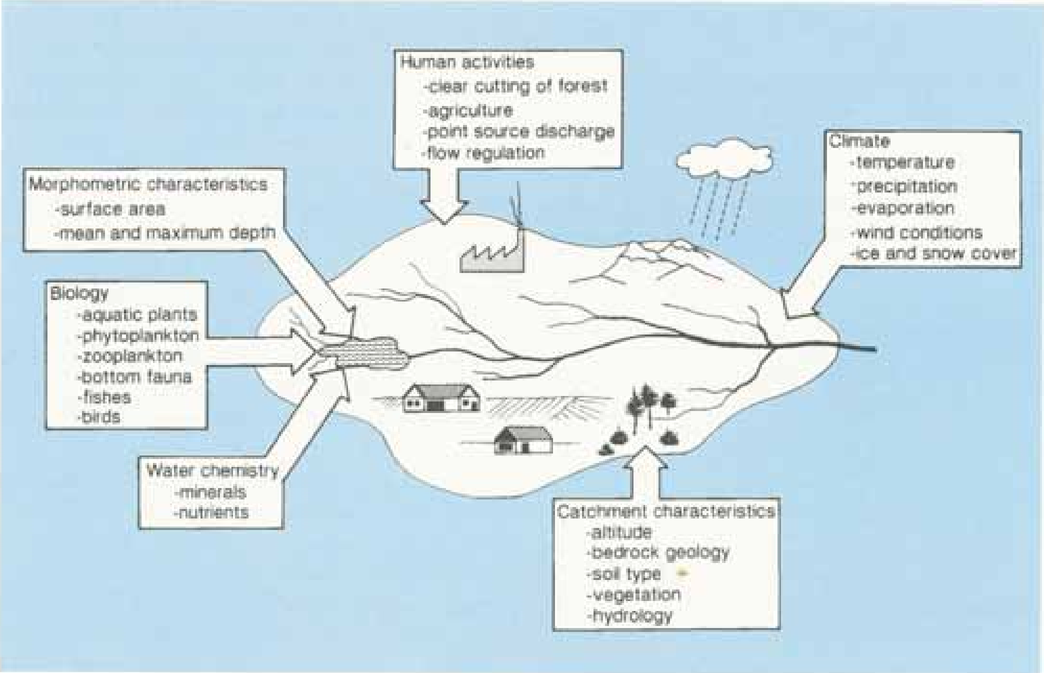


Figure 3:
Conceptual diagram describing river catchment relationships.

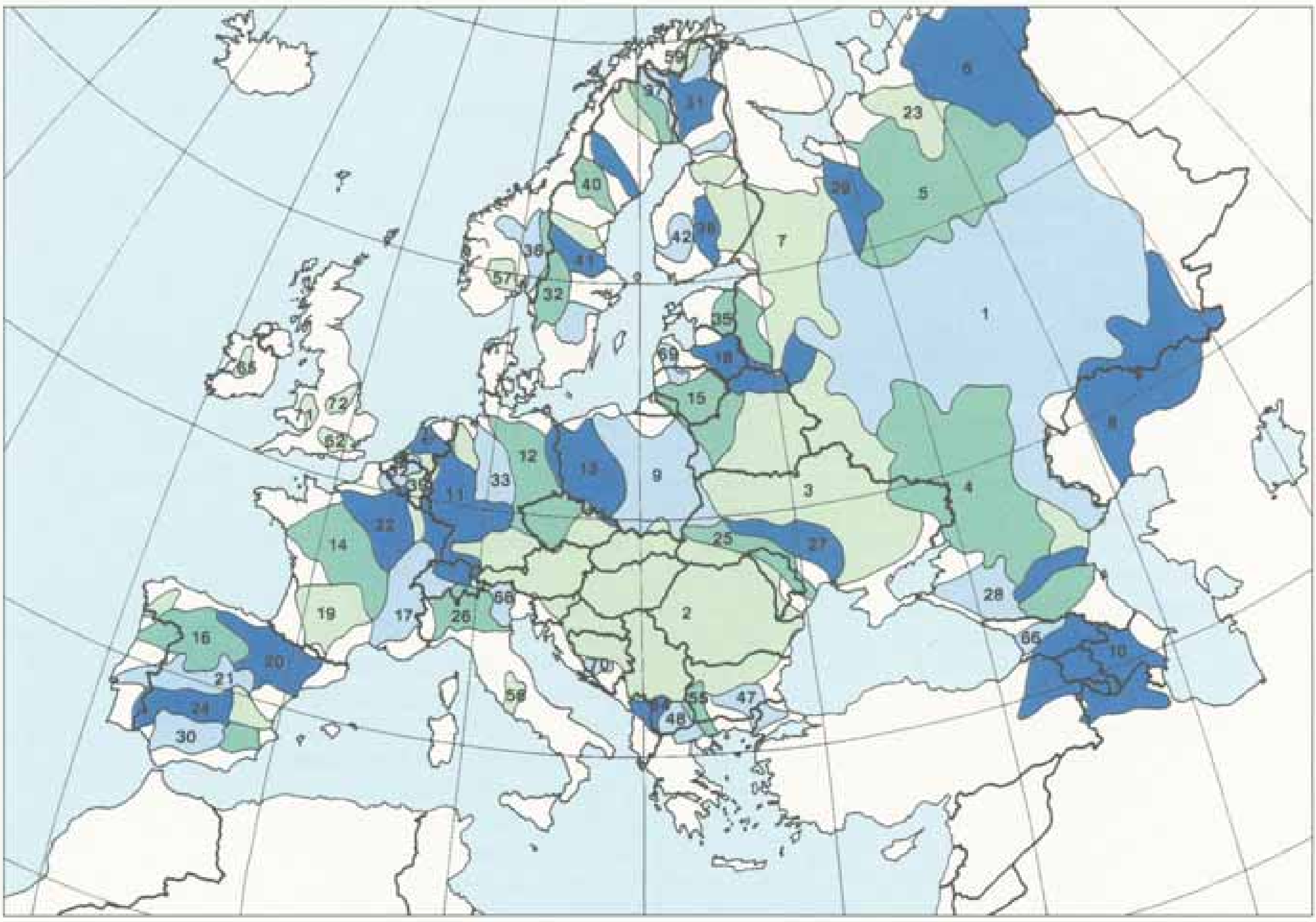


Figure 4: European river catchments exceeding 10 000 km². Numbers refer to *Figure 5* and *Table 4*.

istics of the catchment are important when describing the lake environment. For example, nutrient loading of a lake is determined not only by the bedrock geology and soil type in the catchment, but also by the human activity.

Reservoirs are man-made lakes created to serve one or more purposes. As their water residence time is generally relatively short, and as the water level fluctuates much more widely and frequently than in natural lakes, they can be regarded as hybrids between rivers and lakes. As reservoirs are usually created by flooding river valleys, they are typically long and narrow with an irregular shoreline.

European rivers

Europe is a relatively small continent that comprises only about 7 per cent of the total continental area. European rivers discharge a total of 3100 km³ of fresh water to the sea each year, this being about 8 per cent of total world discharge. Because Europe has a temperate humid climate and a high percentage of limestone in the surface rock, the weathering rate is the highest of all the continents; as a result, 12.6 per cent of all dissolved solids discharged to the oceans are derived from Europe (Kempe et al. 1991). That Europe is relatively densely populated and has a high proportion of agricultural areas also affects the concentration of minerals in river water; thus the median nitrate level is 1.8 mg N l⁻¹ in European rivers as compared with only 0.25 mg N l⁻¹ in non-European rivers (Meybeck et al. 1989).

Major European river catchments

In proportion to its land area, Europe has the longest coastline of all continents. As it is a relatively young and structured continent from the geological point of view, river catchments are numerous but relatively small and rivers are short (*Figure 4*). About 70 European rivers have a catchment area exceeding 10 000 km², and only rivers arising deep inside the continent are relatively large. The three largest rivers in Europe, the *Volga*, the *Danube* and the *Dnepr*, drain one quarter of the continent, but are only small by world standards, their catchments ranking 14th, 29th, and 48th, respectively (Showers, 1989).

The 31 largest European rivers, all of which have catchments exceeding 50 000 km^2, drain approximately two thirds of the continent (*Figure 5*). More than half of these rivers have their catchment area in the former *Soviet Union* (*Figures 4 & 5*). The major rivers flowing north into the Barents Sea and the White Sea are the *Severnyy Dvina* and the *Pechora*. The *Volga* and the *Ural* which flow south and the *Kura* which flows east drain into the Caspian Sea while the *Dnepr* and the *Don* drain south into the Black Sea. The largest river to discharge into the Black Sea is the *Danube*, which has its catchments in 16 countries of central Europe and the Balkans. The main rivers to discharge into the Baltic Sea are the *Neva*, the *Wisla*, the *Oder*, and the *Neman*. Ten rivers with catchments larger than 50 000 km^2 drain into the Atlantic and the North Sea with the *Rhine*, the *Elbe*, the *Loire* and the *Douro* being the largest. The European rivers that drain into the Mediterranean are relatively small, the *Rhône*, the *Ebro*, and the *Po* being the largest. Nevertheless, since the damming of the *Nile*, the *Rhône* has become the Mediterranean's most important freshwater source (Kempe et al. 1991). Four large European river catchments are briefly described in *Box 1*.

Major rivers in European countries

Countries whose coastline is long in relation to their area, for example *Iceland*, *the United Kingdom*, *Ireland*, *Norway*, *Sweden*, *Denmark*, *Italy*, and *Greece*, generally have a large number of relatively small river catchments and short rivers, the three to four largest of which together drain only 15-35 per cent of their area (*Table 4*). The population tends to congregate in towns along the coastline and waste water is consequently discharged directly into coastal areas rather than into the river systems.

In countries without a coastline, for example *Switzerland*, *Austria*, *the Czech Republic*, *the Slovak Republic*, *Hungary*, *Belarus*, and *Moldova*, waste water is discharged solely into inland fresh waters.

Many European countries are drained by only a few river catchments; thus the *Wisła* and *Oder* drain more than 95 per cent of *Poland*, and the *Danube* drains most of *Hungary*, *Romania*, and *Slovenia* (*Table 4*). As countries situated downstream of large transboundary rivers are often dependent on these external sources for most of their freshwater supply, they are very dependent on the quality of the river water. An example is *The Netherlands*, which receives two thirds of its water supply from the *Rhine*.

Photo: Hans Ole Hansen

River	Country (Code refers to *Table 4*)	Catchment area 10^3 km^2	Mean discharge km^3 yr^{-1}	Length km
1. Volga	RU	1360	230	3530
2. Danube	DE,AT,SK,HU,HR, SB,RO,BG,UA, CH*,PL*,IT*,CZ*, SI*,BA*,AL*,MD*	817	205	2850
3. Dnepr	RU,BY,UA	558	53	2270
4. Don	RU,UA*	422	38	1870
5. Servernyy Dvina	RU	358	148	740
6. Pechora	RU	322	129	1810
7. Neva	RU,FI*,BY*	281	79	75
8. Ural	RU,Kazakhstan*	270	-	2540
9. Wisła	PL,SK*,UA*,BY*	194	31	1050
10. Kura	GE,TK,AZ,AR*, Iran*	188	18	1360
11. Rhine	CH,AT,DE,FR,NL, IT*,LU*,BE*	185	69	2200
12. Elbe	CZ,DE,AT*,PL*	148	24	1140
13. Oder	CZ,PL,DE	119	16	850
14. Loire	FR	118	32	1010
15. Neman	BY,LT,RU,PL*	98	22	960
16. Douro	ES,PT	98	20	790
17. Rhône	CH,FR	96	54	810
18. Zapadnaya Dvina	RU,BY,LV,LT*	88	21	1020
19. Garonne	FR	85	21	575
20. Ebro	ES	84	17	910
21. Tajo	ES,PT	82	6	1010
22. Seine	FR	79	16	780
23. Mezen'	RU	78	26	970
24. Guadiana	ES,PT	72	6	800
25. Dnestr	UA,MD	72	10	1350
26. Po	IT,CH*	69	46	670
27. Yuzhnyy Bug	UA	65	3	860
28. Kuban'	RU	58	13	870
29. Onega	RU	57	18	420
30. Guadalquivir	ES	57	2	675
31. Kemijoki	FI	51	17	510

Figure 5:
European main rivers with catchment areas larger than 50 000 km^2.
*: the country is part of the catchment area but the main river does not run through it.

Table 4:
The major European rivers, their catchment area within the country and the percentage of the country area drained.
River numbers refer to *Figures 4 & 5*. Tributary to: #: Danube *: Rhine ◻: Neva §: Kura •:Neman. ~: approximately.

Country (Country code)	**River**	**Catchment** **Area** **10^3 km^2**	 **%** **of country**
Albania (AL)	64 Drin	5.6	20
	87 Seman	5.6	20
	82 Vijosë	4.2	15
Austria (AU)	2 Danube	80.6	96
	# Inn	15.9	19 #
	11 Rhine	2.4	3
Belarus (BY)	3 Dnepr	~130.0	~63
	15 Neman	45.5	22
	18 Zapadnaya Dvina	25.8	12
Belgium (BE)	39 Meuse	13.5	44
	52 Schelde	~10.0	~33
Bosnia-Herzegovina (BA)	# Sava	~37.5	~74 #
	70 Neretva	~10.0	~20
Bulgaria (BG)	2 Danube	48.2	43
	47 Évros	21.1	19
	55 Struma	10.8	10
Croatia (HR)	2 Danube	~ 37.0	~65 #
	# Sava	~24.5	~44 #
	# Drava	~8.0	~14
Czech Republic (CZ)	12 Elbe	51.4	64
	# Morava	~25.0	~30 #
	13 Oder	4.7	6
Denmark (DK)	99 Gudenå	2.6	6
	101 Skjern Å	2.3	5
	103 Storå	1.1	3
Estonia (EE)	34 Narva	~17.0	~38
	81 Pärnu	6.9	15
	102 Jägala	1.6	4
Finland (FI)	◻ Vuoksa	61.1	18 ◻
	31 Kemijoki	51.1	15
	38 Kymijoki	37.2	12
	42 Kokemäenjoki	27.0	9
Former Yugosl. Rep. of Macedonia (MA)	48 Vardar	~20.5	~81
	64 Drin	~3.5	~13
France (FR)	14 Loire	117.5	21
	17 Rhône	85.6	16
	19 Garonne	85.0	16
	22 Seine	79.0	14
Georgia (GE)	10 Kura	~42.5	~61
	66 Rioni	13.4	19
	§ Alazani	7.5	11 §
Germany (DE)	11 Rhine	102.1	29
	12 Elbe	97.0	27
	2 Danube	59.6	17
	33 Weser	45.8	13
Greece (GR)	73 Aliákmon	9.5	7
	80 Piniós	7.1	5
	55 Struma	6.0	5
Hungary (HU)	2 Danube	93.0	100
	# Tisza	44.6	48 #
	# Drava	6.2	7 #
Iceland (IS)	77 Jökulsá-á-Fjöllum	7.8	8
	78 Thjórsá	7.5	7
	84 Ölfusa	6.1	6
Ireland (IE)	65 Shannon, R.	~14.0	~20
	88 Barrow, R.	~5.5	~8
	96 Suir, R.	3.6	5
Italy (IT)	26 Po	69.0	23
	56 Tevere	17.2	6
	68 Adige	12.2	4
Latvia (LV)	18 Zapadnaya Dvina	23.6	37
	75 Lielupe	8.8	14
	74 Gauja	7.9	12
Lithuania (LT)	15 Neman	46.6	71
	• Vilnya	13.8	21 •
	69 Venta	5.2	8
Luxembourg (LU)	* Sûre	~2.0	~77 *
	* Mosel	~0.5	~19 *
Moldova (MD)	25 Dnestr	~18.0	~53
	# Prut	~12.0	~36 #
	94 Kogel'nik	3.9	11
Netherlands (NL)	11 Rhine	~25.0	~60
	39 Meuse	~6.0	14
Norway (NO)	36 Glomma	41.4	13
	57 Drammens-elva	17.1	5
	59 Tana, R.	11.4	4
Poland (PL)	9 Wisla	191.8	61
	13 Oder	114.2	37
	100 Rega	2.6	1
Portugal (PT)	21 Tajo	24.9	27
	16 Douro	18.6	20
	24 Guadiana	11.5	13
Romania (RO)	2 Danube	232.	98
	# Muresul	27.8	12 #
	# Oltul	24.0	10 #
Russian Federation (RU)	1 Volga	1 360.0	35
	4 Don	~380.0	~10
	5 Severnyy Dvina	357.0	9
	6 Pechora	322.0	8
	7 Neva	~220.0	~6
	8 Ural	~110.0	~3
	3 Dnepr	~105.0	~3
Serbia-Montenegro (SB)	2 Danube	~95.0	~93
	# Sava	~20.0	~10 #
	64 Drin	~4.5	~4
Slovak Republic (SK)	2 Danube	~46.5	~97
	# Váh	~17.5	~37 #
	# Tisza	~16.0	~33 #
Slovenia (SI)	# Sava	10.8	53 #
	# Drava	~5.0	~24
Spain (ES)	20 Ebro	84.2	17
	16 Douro	79.3	16
	24 Guadiana	60.3	12
	21 Tajo	56.8	11
Sweden (SE)	32 Göta älv	42.8	10
	37 Torne älv	34.1	8
	40 Ångermanälven	30.6	7
	41 Dalälven	29.0	6
Switzerland (CH)	11 Rhine	28.0	68
	* Aare	17.8	43 *
	17 Rhône	10.4	25
Ukraine (UA)	3 Dnepr	293.0	48
	27 Yuzhnyy Bug	63.7	11
	25 Dnestr	52.7	9
United Kingdom (UK)	62 Thames, R.	15.0	6
	71 Severn, R.	11.6	5

Box 1: Large European river catchments.

VOLGA

The river *Volga* catchment is the largest in Europe. It lies entirely within *the Russian Federation*, comprising about one third of European *Russia*. The *Volga* is a lowland river with its source lying at 228 m a.s.l. in the Valdayskaya Heights. The main river and most of its tributaries flow from the north to the south through several different geographical and vegetational zones, including taiga, hard- and softwood forests, steppes, semi-arid, and arid zones. The major tributaries are the *Oka*, the *Belaya*, the *Vyatka*, and the *Kama*, each of which is longer than 1000 km and has a catchment area exceeding 100 000 km^2. As the *Volga* approaches the Caspian Sea it divides into a delta comprised of about 275 channels covering about 12 000 km^2 (Fortunatov,1979). Annual mean discharge is 230 km^3.

Many of the rivers that comprise the *Volga* river system are highly regulated, the main course itself being characterized by having a large number of reservoirs and no parts remaining with a natural regime unchanged by flow regulation. The reservoirs on the main river and its tributaries cover an area of more than 26 000 km^2 and have a storage capacity of about 90 km^3 (Pavlov & Vilenkin, 1989). They are primarily used for the generation of hydroelectric power and for irrigation purposes. The river system is also utilized for fishery and navigation, and for recreational and domestic purposes. The average population density in the catchment is 35 inhabitants km^{-2}, there being eight cities with more than 1 million inhabitants, the largest of which are Moskva, Volgograd, and Nisjnij-Novgorod.

DANUBE

The *Danube* catchment is the second largest in Europe and spreads through 17 countries. The river rises in *Schwarzwald* in southern *Germany* at 1050 m a.s.l. and runs east through nine of the countries before emptying into the western part of the *Black Sea*. Its major tributaries are the *Inn*, the *March*, the *Drava*, the *Tisza*, the *Sava*, the *Morava*, the *Siretul*, and the *Prut*, all of which are longer than 350 km and have catchments exceeding 25 000 km^2. Before discharging into the Black Sea the *Danube* divides into a delta with three main channels. Annual mean discharge is 205 km^3.

The river system has always been of importance for transportation, and many large cities lie within the catchment, including München, Wien, Bratislava, Budapest, Zagreb, Beograd, Sofiya, and Bucuresti. About 75 million people inhabit the catchment, the mean population density being about 90 inhabitants km^{-2}.

The great energy potential of the river system is utilized by the intensive urban and industrial developments that spread through the catchment. Hence 48 dams transverse the main river itself. Of the numerous industries located in the catchment, those with the greatest impact on the rivers are industries producing paper, pulp, iron, steel, chemical, oil products, and sugar. The tributaries of the *Danube* are often more polluted than the main course itself.

WISLA

The *Wisla* catchment is the ninth largest in Europe. The river rises in the Beskidy Mountains in southern *Poland* at 1100 m a.s.l. and flows north into the Baltic Sea. The catchment lies almost entirely within *Poland* where it drains 61 per cent of the country; smaller parts lie within *the Slovak Republic*, *Belarus*, and *the Ukraine*. The major tributaries are *San*, *Wieprz*, *Bug*, and *Narew*, all of which are longer than 300 km and have catchments exceeding 10 000 km^2. Annual mean discharge is 31 km^3.

In comparison with most other large European rivers the *Wisla* is rather unique in that only short reaches have been regulated (Kajak, 1992). It runs naturally over long stretches and water flow is quite irregular. The central stretch is particularly dynamic, with braided channels, permanent and temporary islands, and rich valley vegetation. The verdant embankments, wetlands, and swamps that are found along most of its course probably remove a significant part of the organic and nutrient pollutants that are discharged into the river; as a consequence they are of considerable importance.

The mean population density in the catchment is 125 inhabitants km^{-2}. The main cities are Warszawa, Kraków and Lódź. As much of Polish heavy industry is located in the upper catchment, the river is polluted almost from its source. Additional waste released at sites along the tributaries strongly affects the entire river. The *Wisla* therefore accounts for a significant proportion of the total riverine pollution of the Baltic Sea (Kajak, 1992).

RHINE

The Rhine catchment is the 11th largest in Europe. The river flows northwards through five countries while the catchment area is spread over eight. It rises in the Swiss Alps 2200 m a.s.l and descends to 200 m before leaving *Switzerland*. During the remaining 950 km it descends only 200 m. The major tributaries are the *Aare*, the *Neckar*, the *Main*, and the *Mosel*, all of which are longer than 300 km and have catchments exceeding 10 000 km^2. In *the Netherlands* the *Rhine* branches into three main rivers before emptying into the North Sea. Annual mean discharge is 70 km^3.

The river flow is balanced by the *Bodensee* as well as by a number of dams along the main river and its tributaries, a factor which has made the *Rhine* one of the worlds most navigated rivers. It has therefore played a vital role in the evolution of the densely populated and heavily industrialized centers in its catchment. The mean population in the catchment is 275 inhabitants km^{-2}. The larger cities include Zürich, Strasbourg, Frankfurt, Düsseldorf, Köln, and Amsterdam.

The *Rhine* catchment has become the most important industrial agglomeration in Europe. It accounts for 20 per cent of the worlds chemical production, and boasts several steel industries, coal mines, power stations, etc. (Lelek, 1989). Until recently many of these industries discharged untreated waste water directly to the river and its tributaries, thereby causing very severe pollution.

River flow

The pattern by which river flow varies during the year, ie. the *flow regime*, is determined by the seasonal variation in climate, as well as the nature of the catchment ie. soil and bedrock permeability, land-management, etc. Flow regimes have their origins in the precipitation that falls over the catchment, in the form of rain and snow. Only a part of the precipitation runs off to the rivers since some of the water evaporates. However, annual run-off generally follows cumulative precipitation in the catchment quite closely. Because climatic and geological properties differ throughout Europe, the flow regimes of European rivers vary considerably. Precipitation is highest in the west of Europe and lowest in the east, while evaporation is highest in the south and east. Annual run-off may exceed 3000 mm in parts of *Iceland*, *Norway*, and the Alps, whereas it is below 25 mm in parts of *Spain* and southern parts of *the Russian Federation*. Similarly, while more than 70 per cent of the precipitation runs off to the rivers in the western and mountainous parts of Europe, only 25-50 per cent becomes run-off in the lowland parts of central Europe, and less than 10-20 per cent in the arid regions.

Seasonal differences within Europe are also reflected by different flow regimes (*Figure 6*). In the central parts of *the Russian Federation* and in northern Europe the period of high flow and river flooding occurs in the spring and summer in connection with the thawing of snow and ice while the low water period occurs during late autumn and winter. An example is *Torne älv* in *Sweden* and *Finland*, where 25 per cent of the river's annual discharge occurs during one summer month, there being almost no flow during the winter months. Similar flow regimes are seen in rivers in more southerly mountainous areas, an example being the *Adige* in *Italy*, which has a typically "Alpine" flow regime, much like that of northern rivers. In the temperate lowlands in southern Europe the rivers are primarily fed by rainfall and the high water period consequently occurs during late autumn or winter. Thus the natural flow regime of the *Tera* in *Spain* used to be characterized by high flow during the winter and spring, and very low flow during the summer (this has now been modified by human activity, as described below). Rain-fed rivers generally have a less regular flow regime, and discharge in small rivers may be rapidly changed by local rain storms. Many rivers on the European main-

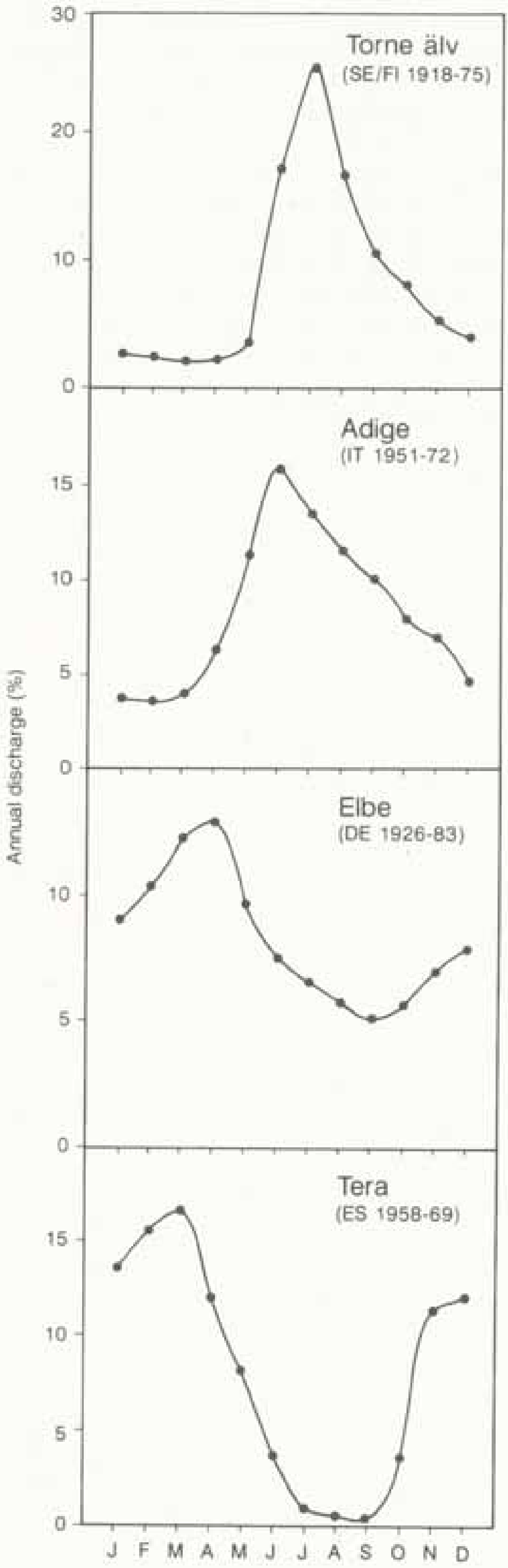


Figure 6:
Percentual flow regime of Torne älv[1], Adige[2], Elbe[3], and Tera[4] rivers.
(Revised from: [1]Petersen et al. 1992; [2]Duzzin et al. 1988; [3]Wassergütestelle Elbe, 1990; [4]Casado et al. 1989.)

land have a much less fluctuating flow regime, although flow is generally highest during the winter half-year, and lowest during the summer half-year. An example is *the Elbe*.

When extensive swamps, forests, and lakes are present in a river catchment they attenuate the natural fluctuation in discharge by storing the water and releasing it slowly. Human activity may also affect river flow regimes, either by attenuating the fluctuations of the natural flow regime, for example by damming (*Figure 7*), or by further enhancing the fluctuations, for example by water abstraction for irrigation purposes during dry periods.

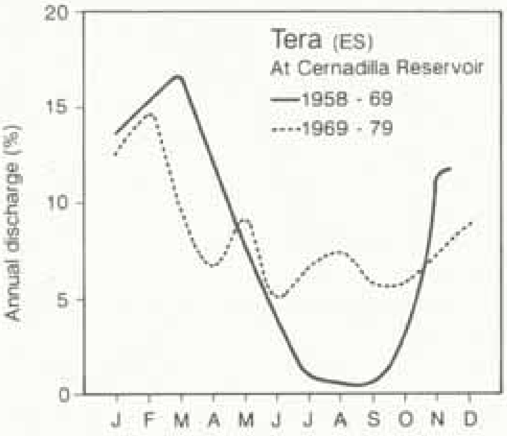


Figure 7:
Percentual flow regime of the Tera river in Spain, before (1958-69) and after (1969-79) the building of the Cernadilla reservoir.
(Revised from Casado et al. 1989.)

It is important that the river flow regime is taken into account when assessing the capacity of a river to tolerate a pollutant because the damage caused largely depends on its final concentration, and therefore on the amount of water in which it is diluted. Consequently it is important that a pollutant which is normally sufficiently diluted when flow is normal, does not exceed critical concentrations during periods of low flow.

The amount of water in a river is important for the organisms that live in it, rivers with a constant flow regime generally possessing a more diverse flora and fauna than rivers with widely fluctuating flow regimes.

European lakes and reservoirs

Many natural European lakes appeared 10-15 000 years ago, being formed or reshaped by the last glaciation period, the Weichsel. The ice sheet covered all of northern Europe, but in central and southern Europe it was restricted to the mountain ranges. As a rule the regions that have many natural lakes are those that were affected by the Weichsel ice. *Norway, Sweden, Finland*, and the Karelo-Kola part of *the Russian Federation* have numerous lakes that account for approximately 5-10 per cent of the surface area. Large numbers of lakes were also created in the other countries around the Baltic Sea, as well as in *Iceland, Ireland*, and the northern and western parts of *the United Kingdom*. In central Europe most natural lakes lie in mountain regions, those at high altitudes being relatively small and those in the valleys being the largest, for example *Lac Léman, Bodensee*, and *Lago di Garda* in the Alps and *Prespansko Jezero* and *Ohridsko Jezero* in the Dinarian Alps. An exception is the two large lakes, *Lake Balaton* and *Neusiedler See*, that lie on the Hungarian Plain.

In contrast to glaciation, processes such as tectonic and volcanic activity have only played a minor role in the formation of European lakes. Numerous lakes have been created by natural damming of rivers and coastal areas, however.

Countries that were little affected by the glaciation period have few natural lakes, for example *Portugal, Spain, France, Belgium, southern England*, central *Germany, the Czech Republic, the Slovak Republic*, and the central European part of *the Russian Federation*. In these areas man-made lakes such as reservoirs and ponds are often more frequent than natural lakes. Many river valleys have been dammed to create reservoirs, and a large number have been built in mountain ranges for use by the hydroelectric industry. In several countries, for example *The Netherlands, Germany, France*, and the former *Czechoslovakia*, numerous small artificial lakes have been created by other human activities such as peat and sand quarrying, and for use as fish ponds.

Lakes in Europe

There are more than 500 000 natural lakes larger than 0.01 km^2 (1 ha) in Europe; of these about 80-90 per cent are small with a surface area between 0.01 and 0.1 km^2, and only about

16 000 have a surface area exceeding 1 km² (*Table 5*). Three quarters of the lakes are located in *Norway, Sweden, Finland*, and the Karelo-Kola part of *the Russian Federation*.

The approximate number and size distribution of lakes is shown for each country in *Table 6*; however, the number of small lakes is somewhat uncertain, the figures as a rule being minimum estimates.

Man-made lakes

Reservoirs are the most important man-made lakes in Europe, there being more than 10 000 major reservoirs covering a total surface area of more than 100 000 km². The number of relatively large reservoirs is greatest in *the Russian Federation* (ca. 1250), *Spain* (ca. 1000), *Norway* (ca. 810), and *the United Kingdom* (ca. 570). Other countries with a large number of reservoirs are *Hungary* (ca. 300), *Italy* (ca. 270), *France* (ca. 240), and *Sweden* (ca. 225). Many European countries have numerous smaller man-made lakes, for example *Latvia, Bulgaria*, and *Estonia* which have about 800, 494 and 60, respectively.

Large lakes and reservoirs in Europe

There are 24 natural lakes in Europe that have a surface area larger than 400 km², the largest being *Lake Ladoga* which covers an area of 17 670 km² (*Figure 8*). The latter is located in the north-western part of *the Russian Federation* together with *Lake Onega*, the second largest lake in Europe. Both are considerably larger than other European lakes and reservoirs, but nevertheless rank only 18th and 22nd in world order (Herdendorf, 1982). The third largest European freshwater body is the 6450 km² *Kuybyshevskoye* reservoir on the *Volga*.

Another 19 natural lakes larger than 400 km² are found in *Sweden, Finland, Estonia*, and the north-western part of *the Russian Federation*, and three in central Europe - *Lake Balaton, Lac Léman*, and *Bodensee* (*Figure 8*).

The six largest reservoirs (*Figure 8*) are located in the *Volga* river system in *the Russian Federation*, the two largest being the 6450 km² *Kuybyshevskoye* and the 4450 km² *Rybinskoye* reservoirs. Of the thirteen European reservoirs with an area exceeding 1000 km², only the Dutch reservoir *IJsselmeer* lies outside *the Russian Federation* and *the Ukraine*.

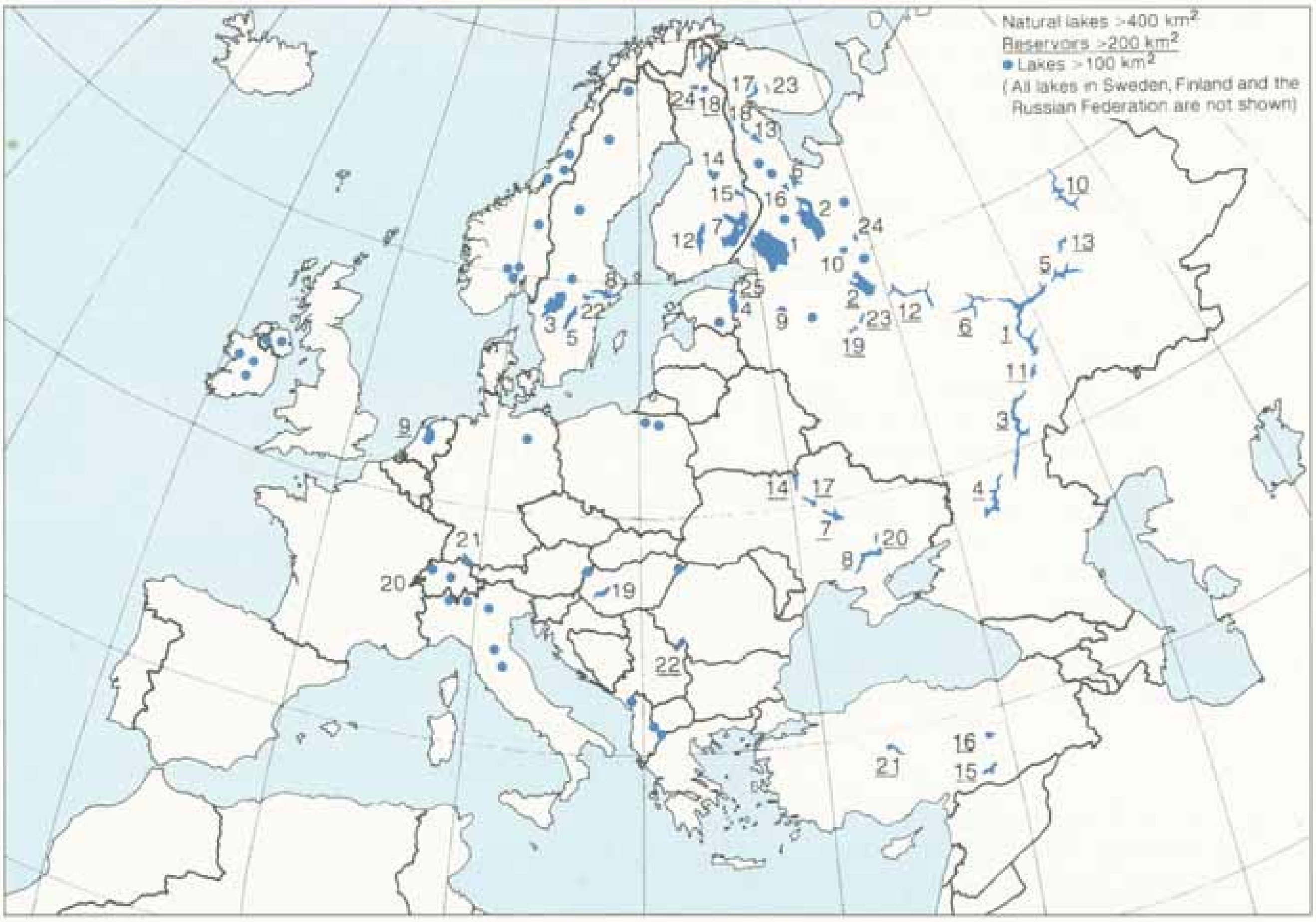
Table 5:
Estimated number of natural lakes in different surface area classes.

Surface area (km²)	Total in Europe	Norway, Sweden, Finland, and Karelo-Kola part of the Russian Federation
> 400	24	21
> 100	150	125
> 10	2000	1500
> 1	16 000	12 500
> 0.1	100 000	75 000
> 0.01	500 000-700 000	> 450 000

Table 6:
Number of lakes in different European countries.

Country	Surface area (km²) 0.01-0.1	0.1-1	1-10	10-100	>100
Albania[1]	-	-	-	> 3	3
Austria[1]	Some 100s		19	7	2
Bulgaria[1]	53	175	288	14	0
Croatia[1]	-	1	3	0	0
Denmark[1]	354	256	74	6	0
England & Wales[1]	1665		50	2	0
Estonia[1]	750	209	41	1	3
Finland[1]	40 309	13 114	2283	279	47
France[2]	-	128	23		1
Georgia[1]	799	58	21	14	0
Germany[3]	-	-	~ 100	~ 20	2
Greece[3]	-	-	-	> 16	1
Hungary[1,4]	-	-	-	2	2
Iceland[1]	~ 7000	1650	176	17	0
Ireland[3]	-	-	~ 100	14	3
Italy[5]	-	> 168	> 82	13	5
Latvia[1]	2164	740	122	20	0
Moldova[1]	> 3300	48	30	6	0
Netherlands[1]	-	-	-	47	3
Norway[1]	208 000		2000	450	7
Poland[1]	6050	2627	545	32	2
Russian Federation[1]	471 000		4626	412	51
Spain[1]	-	-	-	800	
Sweden[1]	59 500	19 374	3990	358	22
Switzerland[6]	1300		10	15	5
Ukraine[1]	950			> 4	2
Former Yugoslavia[6]	> 200		> 10	15	4

- : Information lacking.
There are no or only a few lakes in Belgium, the Czech Republic, the Slovak Republic, Luxembourg, and Portugal. There are no informations from Belarus, Romania, and Lithuania.
Information obtained from: [1]Questionnaires ; [2]Ministere de la Culture et de l'Environnement, 1975 ; [3]Estimated by NERI; [4]Biró, 1984; [5]Gaggino et al. 1987 ; [6]Dill, 1990.



Natural lake	Country (Code refers to *Table 4*)	Area km²	Mean depth m	Max. depth m
1. Ladoga (Ladozhskoye)	RU	17 670	51	258
2. Onega (Onezhskoye)	RU	9670	30	120
3. Vänern	SE	5670	27	106
4. Peipus	RU,EE	3570	23	47
5. Vättern	SE	1912	39	128
6. Vygozero	RU	1285	7	19-24
7. Saimaa	FI	1147	12	82
8. Mälaren	SE	1140	13	61
9. Il'men'	RU	1124	2.6	10
10. Beloye	RU	1120	4.2	20
11. Inari	FI	1102	14	96
12. Päijänne	FI	1054	17	98
13. Topozero	RU	1025	15	56
14. Oulujärvi	FI	893	7.6	35
15. Pielinen	FI	867	9.9	60
16. Segozero	RU	781-910	23	97
17. Imandra	RU	845	16	67
18. Pyaozero	RU	660-754	15	49
19. Balaton	HU	596	3	11
20. Lac Léman	CH,FR	584	153	310
21. Bodensee (Constance)	DE,CH,AT	540	90	252
22. Hjälmaren	SE	478	6.1	22
23. Umbozero	RU	422	30	115
24. Vozhe (Charonda)	RU	420	1.4	5

Reservoirs	Country (Code refers to *Table 4*)	Area km²	Mean depth m	Max. depth m
1. Kuybyshevskoye	RU	6450	12.6	40
2. Rybinskoye	RU	4450	5.6	30
3. Volgogradskoye	RU	3320	10.1	41
4. Tsimlyanskoye	RU	2702	8.8	-
5. Nizhnekamskoye	RU	2650	4.9	-
6. Cheboksarskoye	RU	2270	6.1	-
7. Kremenchugskoye	UA	2250	6.0	-
8. Kakhovskoye	UA	2150	8.5	-
9. IJsselmeer	NL	2000	-	-
10. Kamskoye	RU	1915	6.4	29
11. Saratovskoye	RU	1830	7.3	32
12. Gor'kovskoye	RU	1591	5.5	21
13. Votkinskoye	RU	1120	8.4	28
14. Kiyevskoye	UA	922	4.0	-
15. Ataturk	TR	815	-	-
16. Keban	TR	675	-	-
17. Kanevskoye	UA	582	4.3	-
18. Lokka	FI	417	-	-
19. Ivankovskoye	RU	327	3.4	-
20. Dnieper	UA	320	-	60
21. Hirfanli	TR	263	-	-
22. Djerdap	SB,RO	253	-	92
23. Uglich	RU	249	5.0	-
24. Porttipahta	FI	214	-	-
25. Narva	EE,RU	200	1.9	9

Figure 8:
Large European lakes and reservoirs. (Reservoir numbers underlined).

Depths of lakes and reservoirs

Lake water depth is an important parameter with which to characterize the lake environment. It is largely determined by the surrounding topography, lakes in mountainous regions generally being deeper than in lowland areas. In two lowland countries, *Finland* and *Poland*, the majority of lakes have a mean depth between 3-10 m (*Figure 9*), lakes with a mean depth greater than 10 m rarely being found. In *Austria* and *Switzerland*, in contrast, large shallow lakes are virtually absent, and most lakes have a mean depth greater than 25 m. As with natural lakes, the deepest reservoirs are located in mountainous regions of countries such as *Norway, Spain, France, Scotland*, and *Greece*. Examples are the 190 m deep Spanish reservoir *Almendra*, the 132 m deep Greek reservoir *Kremasta*, and the 125 m deep Norwegian reservoir *Blåsjø* (maximum depths).

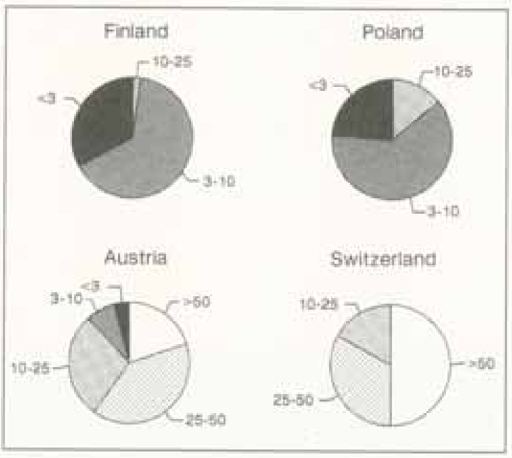


Figure 9:
Frequency distribution of mean depth in lakes larger than 1 km² (Poland > 0.5 km²).

Photo: Martin Søndergaard

Photo: Hans Ole Hansen

3 Water quality of European rivers and lakes

Ecology of rivers and lakes

The physical characteristics of a river, eg. current, gradient, temperature, continuously change as the river progresses from its source to its mouth. Thus a river typically begins as a small, cold, fast flowing and turbulent stream with a bed of large stones or pebbles, but slowly grows in size and depth as tributaries merge into it downstream; the gradient and current decrease, and the river bed becomes sandy and silty. The chemical characteristics of river water also vary considerably from reach to reach, reflecting both local and upstream conditions. Thus as a river system is a continuum of habitats that vary according to local physical and chemical conditions, it is able to support an impressive array of biological communities along its entire length.

The current is the physical characteristic of rivers that mostly influences biological communities. The variable rate at which bottom material is sorted as the river progresses from the rapidly flowing upstream reaches to the slow-moving, often lake-like downstream river courses produces a great variety of substrates for the colonization and development of biological communities. In the fast flowing reaches everything that is not attached or sheltered is swept away by the current, this applying to both organisms and sediment particles. The greater the current, the larger the amount and size of particles that can be carried by the flowing water. The only plants present are sessile algae attached to exposed stone surfaces, rooted plants being absent because of the fast flow and the lack of a fine sediment in which to grow. To avoid being swept away the benthic invertebrates present usually live on or in the shelter of the stones and are structurally adapted to the fast current. The fish are also dependent on the shelter provided by stones or the bank. In slowly flowing rivers, in contrast, rooted plants are abundant in unshaded areas and the fauna is dominated by animals associated with the vegetation or living in the sediment. In the larger rivers phytoplankton may play an important role as primary producers.

In addition to internal primary production, an important source of energy in river ecosystems is externally supplied organic matter. Whereas in small streams most of the organic input is derived from the terrestrial environment, reduced bank shading in the mid-sized rivers makes internal primary production the dominant source of organic matter. In large rivers most of the organic input is derived from upstream reaches and tributaries, as well as from the periodic flooding of adjacent floodplains.

Standing water is the most distinctive characteristic of lakes, and their size and depth significantly influences their ecology. The water in shallow lakes is usually well mixed all the year round whereas lakes deeper than 5-10 m are usually thermally stratified in the summer, with a well mixed surface layer and a separate, more stagnant bottom layer.

Lakes have a number of typical biological communities, each of which depends on primary production of organic matter by phytoplankton and higher plants. Primary production in undisturbed lakes is generally limited by the availability of nutrients and of light. Thus the dominant primary producers are rooted plants in lakes with water so shallow, that the light can penetrate to the lake bottom, but free-floating phytoplankton in lakes with deeper water. The phytoplankton are eaten by the zooplankton which in turn are eaten by larger zooplankton and fish. Phytoplankton that settle to the lake bottom are consumed by benthic invertebrates or decomposed by bacteria.

Lake water nutrient levels are extremely dependent on external nutrient loading, and thus on the characteristics of the lake catchment. The nutrient levels generally determine the magnitude of a lake's primary production,

Photo: Jens Rasmussen

and to some extent the relative importance of the various biological communities. Because lakes with high nutrient levels tend to be dominated by phytoplankton, light cannot penetrate to the lake bottom and the rooted plants therefore partially or totally disappear.

Flood plains and wetlands alongside rivers and lakes are highly productive ecosystems; they provide important feeding and breeding areas for insects, fish, and birds, and serve as nutrient sinks that reduce nutrient and organic matter pollution of the aquatic environment. Wetlands also have a considerable water retention capacity, and therefore play an important role in the regulation and maintenance of river flow. In drained wetlands, however, the natural vegetation is superseded by dry land vegetation and erosion increases, with very serious consequences for the fauna. Although many flood plains were originally forested, at least along the channels, cultivation and urbanization of these rich and fertile areas have resulted in the forest being cleared.

Environmental problems in rivers and lakes

A wide range of human activities may lead to environmental deterioration of inland surface waters, either directly or indirectly (*Box 2*). While the use of inland surface waters for waste disposal has an obvious effect, land use in the catchment area may have an indirect effect on the hydrological cycle (eg. through land drainage and irrigation) or on the water quality (eg. through the runoff of fertilizers and pesticides). Although most environmental problems have evolved gradually with the environmental impact slowly becoming more and more apparent and measurable, severe damage has often occurred before the magnitude of an environmental problem is recognized and the necessary control measures implemented.

Box 2:
Major anthropogenic activities affecting river systems (Boon, 1992).

Supra-catchment effects
Acid deposition
Inter-basin transfers

Catchment land-use change
Afforestation and deforestation
Urbanization
Agricultural development
Land drainage/flood protection

Corridor engineering
Removal of riparian vegetation
Flow regulation - dams, channelization, etc.
Dredging and mining

Instream impacts
Organic and inorganic pollution
Thermal pollution
Abstraction
Navigation
Exploitation of native species
Introduction of alien species

Water pollution and wasteful use of freshwater threaten socio-economic development and affect the ecological quality of the water bodies. Water quality is the term which expresses the suitability of water to sustain both various human and ecological uses. Any particular use has specific requirements for as to water quality. High concentration of organic matter and consequently low oxygen levels, for example, limit the existence of aquatic animals, and toxic substances restrict the use of water for drinking. Water quality is therefore defined by the range of variables which limits water use. An optimal water quality can be defined as the quality which enables native species to occur in stable, well balanced populations, and which does not limit and affect the value of water as a resource.

Pollution

As all water bodies have some regenerative capacity, they are usually able to absorb a certain amount of pollution without long lasting untoward consequences. However, the effects of pollutants discharged into inland surface waters are wide ranging; some can be toxic to humans and to the aquatic biota when exceeding critical concentrations, while others may impair the environmental conditions for certain species, for instance by interfering with reproductive capacity of a species and thereby rendering it unable to compete with other species. The effects of other pollutants are often more indirect; for example, nutrient discharge into a lake will lead to increased phytoplankton production and turbid water, thereby changing the ecological structure and rendering the water unsuitable for drinking or bathing; similarly, severe organic matter pollution of rivers may lead to oxygen depletion and high ammonium levels – conditions which are unfavourable for benthic invertebrates and fish.

The environmental effect of a pollutant depends mainly on its concentration or the total loading, but also on numerous other factors. For example, resistance to pollutants generally rises with age, eggs being more susceptible to some pollutants than newly hatched larvae. The amount and concentration of a pollutant present in a water body depends on a number of factors, including:

– *The intensity and nature of the source.* While pollutants derived from sewage treatment plants are discharged evenly throughout the year, loading by other pollutants may be more seasonal, eg. pesticides from the spraying of agricultural land in the spring and summer.

– *The size and renewal time of the water body.* The amount of water into which the pollutant is discharged and hence diluted determines its concentration. If an identical amount of a pollutant is discharged into a large and a small river, the effects will generally be most harmful in the small river. Another aspect to be considered is that river flow changes during the year; thus as the dilution of a pollutant is minimal when water flow is low, it will have a more serious negative impact than when water flow is high.

Sources of pollution discharge into rivers and lakes

Although humans have probably always used rivers and lakes for waste disposal purposes, most environmental problems have arisen in the last centuries, the discharge of many pollutants being directly related to population density and to the development of sewerage systems. The European population increased rapidly during the 19th century, and more gradually during the 20th century, eg. from 691 million in 1970 to 777.5 million in 1989 ("Europe's Environment – The Dobříš Assessment" (1994)). The urban population has also increased and at present 70 per cent of the European population lives in cities. This, together with the economic growth and the construction of sewerage systems, has resulted in a sharp rise in the production and discharge of waste water into inland surface waters. The main sources and the current trends in pollutant discharge to European surface waters are briefly summarized below.

Organic matter in domestic and industrial waste water

Organic matter discharged into rivers and lakes in the form of domestic waste water and industrial effluent, especially from the food processing and paper industries, is a major source of pollution. The population increase and rapid economic growth have resulted in an increase in this discharge. Measures to counteract the increase have recently been implemented in many European countries, mainly by the construction of biological sewage treatment plants able to reduce the amount of organic matter by 90 per cent or more. Thus in many nordic and western European countries more than 60 per cent of the population is served by efficient waste water treatment plants. However, in some Mediterranean and most eastern European countries, only a minor part of the population is served by sewage plants able to effectively remove organic matter.

Phosphorus

Phosphorus causes eutrophication problems in many lakes and reservoirs. Global production and use of phosphorus have sharply increased since the end of World War II, European countries using about 50 per cent of the total world production (Kaarstad, 1989). Most of the phosphorus is used in fertilizers, but some is also used in detergents and other industrial products. In densely populated areas most of the phosphorus loading of fresh water is derived from human waste products, phosphorus production being 1-1.5 kg P individual^{-1} yr^{-1} in industrialized countries (Jones et al. 1979). The extent to which this is discharged into rivers and lakes depends on the sewage treatment facilities available; mechanical sewage treatment plants are only able to remove a minor part of the phosphorus from waste water, whereas plants with biological treatment and chemical precipitation of phosphorus may remove more than 95 per cent. Waste water treatment plants incorporating phosphorus removal have been constructed in Europe during the last fifteen years, especially in the nordic and western European countries. Similary, many countries have lowered the phosphorus content of detergents, thereby lowering phosphorus loading of inland surface waters. However, at present the majority of European waste water treatment plants have only limited ability to remove phosphorus.

Industrial effluents

During the last centuries there has been a sharp increase in European industrial production and consequently in the amount of industrial waste water. The pollutant composition of industrial waste water depends on the products being produced, and therefore varies greatly. Growing awareness of environmental problems has led to improved industrial waste water treatment especially in western European countries, and the use of some highly toxic pollutants (eg. PCB's) has either been restricted or their discharge reduced significantly through improved waste water treatment. However, many highly polluting industries still remain, particularly in eastern Europe where investment in waste water treatment facilities is badly needed.

Mining

European mining production of coal and lignite, metals, and salts increased sharply during the 19th and 20th century; for example, zinc production quadrupled between 1950 and the end of the 1970s, and that of cadmium increased six-fold in the same period. Such mining activities often lead to environmental problems in downstream rivers and lakes as a result of the usage of large quantities of water and the discharge of waste products. De-watering of deep coal mines may result in the production of large amounts of saline water, an example being *Poland* where the daily production is 7000 tonnes of salt. The acidic leachate from coal mines can also contain large amounts of dissolved solids (RIVM/GLOBE, 1992). Metal ore mining generally leads to the production of waste water containing high concentrations of metals. Although growing awareness of the resultant environmental problems has led to measures being taken to reduce the negative impact of mining on inland surface waters, waste products from mining still have a negative impact on the environmental state of many European rivers and lakes.

Photo: Peter Bang/BIOFOTO

Agriculture

The environmental state of European inland surface waters is affected by numerous agricultural activities, including dredging and drainage of wetlands, the use of water for irrigation, the application of fertilizers and pesticides, and physical or mechanical activities such as tilling, ploughing, and harvesting. More than 30 per cent of the land area of Europe is used for agricultural production, although there are large regional differences in the percentage of farm land, farming intensity, and the type of crops grown. For example, agricultural land constitutes about 65 per cent of the total land area in *Denmark*, 81 per cent in *Ireland*, and 8 per cent in *Sweden*. Similarly, while 60 per cent of the total land area is arable land in *Denmark*, only 18 per cent is arable land in *Ireland*, most of the agricultural land being used for grazing ("Europe's Environment – The Dobříš Assessment" (1994)). The application of fertilizers and pesticides varies according to the kind of crops grown and the intensity of agricultural production; thus in countries with a very efficient agricultural sector such as *The Netherlands* and *Denmark*, animal fertilizer usage is currently 225 and 135 kg nitrogen per hectare of agricultural land, respectively, while it is only around 50 kg in many southern European countries, and 70-90 kg in eastern European countries such as *Poland* and *Bulgaria*.

European agricultural production has gradually increased during the last forty years, the increase having been most marked in western European countries. This has mainly been achieved by structural changes such as increased mechanization (eg. tractors), specialization (eg. monoculture), and by the application of fertilizers and pesticides. Per hectare usage of nitrogen fertilizers increased by 68 per cent between 1970 and 1990, and that of pesticides increased even more. As Europe has lost much wetland during the last centuries, the capacity of freshwater ecosystems to store and decompose many pollutants has been significantly reduced.

Pollution control measures and future environmental problems

That human activity causes serious environmental problems has now been recognized, and measures to reduce pollution have been implemented with varying degrees of success. Organic matter and phosphorus discharges have been reduced markedly in several areas during the last fifteen years, and the use and discharge of some harmful products (eg. heavy metals, DDT, PCB's) has also been restricted.

Control of pollutant discharge has generally been most effective in the case of point sources such as municipal sewage water and industrial effluents, and in the case of pollutants whose use has been restricted or completely banned. In the case of non-point source pollution, eg. nitrate in runoff from agricultural land, efficient control has rarely been achieved. No doubt non-point pollution will be one of the major environmental problems of tomorrow.

Also, the production and potential release of new synthetic organic compounds into the environment, together with problems related to climatic change, ozone depletion, and acidification, currently pose serious threats to the aquatic environment in Europe.

Regulation of European rivers

River regulation is a general term describing the physical changes that man imposes on watercourses. Various human activities that physically influence rivers are listed in *Box 3*.

Box 3:
Major human activities physically influencing river systems.

Land drainage
Flood protection
Reservoirs
Dams
Weirs
Channelization
Inter-basin water transfer
Navigation
Dredging
Water abstraction

Many of the rivers in Europe have now been regulated (Brookes, 1987; Petts, 1988; García de Jalón, 1987). River regulation has been undertaken to the greatest extent in western and southern Europe. Thus in *Belgium*, *England*, *Wales*, and *Denmark*, the percentage of river reaches that are still in a natural state is less than 20 per cent. In contrast, in countries such as *Poland*, *Estonia*, and *Norway*, the rivers still have 70-100 per cent of their reaches in a natural state.

River regulation often causes major changes in river processes, primarily the flow regime and the transport of dissolved and particulate matter. The effects are seen not just locally, but often extensively. Downstream reaches and their surrounding areas are nearly always affected, but upstream reaches are affected as well. Some types of river regulation may affect most of a catchment area, for example land drainage, but construction of reservoirs has the most widespread and marked effect. The effects of channelization in lowland rivers are generally restricted to the rivers and their immediate surroundings.

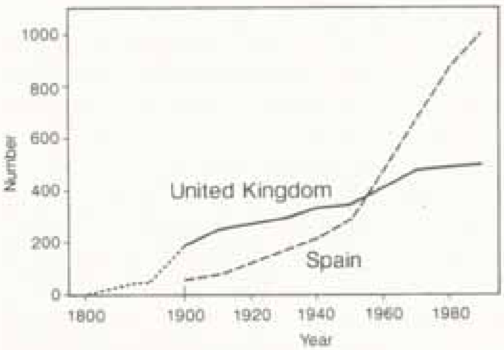


Figure 10:
The increase in total number of reservoirs in the United Kingdom with dams higher than 15 m, and in Spain with area > 8 km^2.
(From Boon, 1992 and Riera et al. 1992).

Reservoirs

Reservoirs usually have a relatively short water residence time – often less than a year and sometimes just a few days. They can therefore be regarded as a hybrid between a river and a lake that can be divided into three zones: a river-like zone at the inflow end, a lake-like zone at the outflow end, and a transitional zone in between. Another prominent feature of many reservoirs is that the water level fluctuates widely through the year, the result being that the littoral zone is biologically poorly developed.

Reservoirs have been constructed in Europe for thousands of years, the earliest having been relatively small, and mainly used for domestic water supply and crop irrigation. During the last two centuries there has been a marked increase in both reservoir size and number, large storage capacity reservoirs having been constructed in many countries, especially in the former *Soviet Union*. Thus there are currently about 3900 large reservoirs with dams higher than 15 m in Europe excluding the former *Soviet Union*, half of which have been built since 1961 (Boon, 1992). To this must be added the many large reservoirs in the European part of the former *Soviet Union*, and the thousands of smaller reservoirs and ponds spread throughout Europe.

The development of reservoir construction in Europe can be illustrated using *the United Kingdom* and *Spain* as examples (*Figure 10*). In *the United Kingdom* the number of reservoirs grew rapidly during the second half of the 19th century from about 50 to about 200; from then until the mid 1970s, the rate was about six new reservoirs per year (Boon, 1992). In *Spain* the number of reservoirs grew at the rate of about two per year between 1900 and World War II, but at a rate of about 20 per year in the post-war period from 1950 to 1980 (García de Jalón, 1987; Riera et al. 1992). Reservoir construction in Europe has now fallen off and growth in total reservoir area seems to be stagnant. This is mainly because of the lack of suitable sites (Williams & Musco, 1992), several reservoirs having already been built along many European rivers (*Figure 11*).

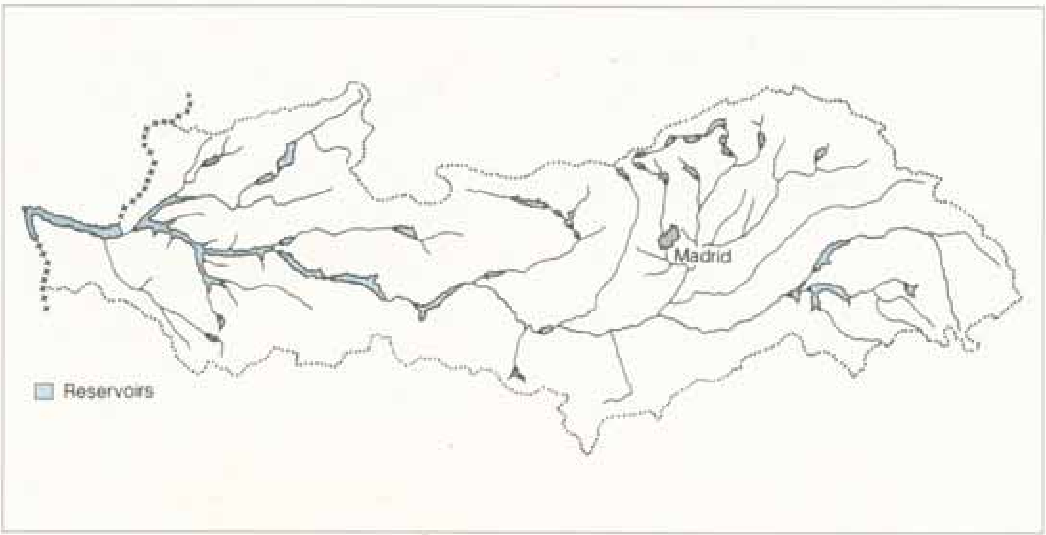


Figure 11:
Location of reservoirs along the Spanish part of the river Tajo.

Photo: Steen Lund/BIOFOTO

Types of reservoirs

European reservoirs are of two main types: highland reservoirs and lowland reservoirs. Highland reservoirs are located in mountain regions and are characteristically elongated in shape and relatively deep. Lowland reservoirs are located in river valleys and are characteristically more circular in shape and relatively shallow. As population density is usually much higher in lowland areas, anthropogenic impact on lowland reservoirs tends to be greater than that on highland reservoirs.

Reservoir usage

Reservoirs, being man-made, have always been built to serve a purpose. Nowadays however, reservoirs are usually built to serve several purposes, the primary uses typically being the generation of hydroelectric power, irrigation, flood control, and domestic and industrial water supply. Other uses are commercial fishery and various recreational activities.

Hydroelectric power constitutes approximately 12 per cent of the electricity produced in the EC, the three largest producers, *France*, *Italy*, and *Spain*, together accounting for 75 per cent of the total (Williams & Musco, 1992). Reservoirs for hydroelectric power are also found in other European countries with mountainous regions, for example *Norway* and *Sweden* where about 100 and 50 per cent, respectively, of the annual production of electricity is derived from hydroelectric power plants (Energy statistics, 1991; Statistics Sweden, 1990).

In densely populated areas such as London, the Ruhr district, and Madrid, large numbers of relatively small reservoirs provide the urban water supply, as is also the case in many central and east European regions and cities. In several countries, many new irrigation reservoirs have been constructed during recent years in connection with an increase in the area of irrigated land.

Environmental problems related to reservoirs

Reservoir construction leads to a number of environmental problems, both during the building phase and following completion. As the water level in the reservoir rises upon the closing of the dam, major changes take place in the inundated area; farmland can be lost, settlements flooded, and the groundwater table elevated. Once the reservoir has been established, the environmental problems can be divided in two groups: those that render the reservoir unsuitable for its purpose, for example phytoplankton and toxic substances in reservoirs used for drinking water, and those that induce ecological deterioration of the river system, especially downstream of the reservoir (*Box 4*).

Box 4:

Environmental problems related to reservoirs

- Contamination (eg. oil products, heavy metals, pesticides, radionuclides)
- Eutrophication (phytoplankton blooms)
- Obstruction of faunal migration in the watercourse
- Reduction of biological diversity in and downstream of the reservoir

The water quality of a reservoir, as reflected by the content of pathogens, toxic chemicals and poisonous phytoplankton, is of primary concern when the reservoir is used for drinking water, commercial fishery, industrial processes, and recreational activities such as bathing and water sports. At present it is not possible to give a general overview of the extent to which European reservoirs are contaminated with toxic substances. However, contamination of reservoirs with oil, organic solvents, heavy metals and radioactive isotopes has been reported to be a problem in *the Russian Federation* and in *the Ukraine* (Mnatsakanian, 1992; Gavrilov et al. 1989). Many of the environmental problems in reservoirs also occur in natural lakes and rivers, for example eutrophication and heavy metal and organic pollution.

Since reservoirs interrupt the natural continuity of a river, the ecological consequences are manifold. Access to spawning sites for migratory fish is prevented, which significantly reduces the populations of salmon, trout, and sturgeon. As reservoirs trap the suspended matter flowing into them, they reduce the material transport of suspended matter to downstream reaches; in reservoirs with a high phytoplankton productivity, the organic load to the downstream reaches increases. The different quality and nature of the suspended matter downstream reservoirs significantly influence the benthic communities and river metabolism. Reservoirs regulate the water flow, which may result in sudden downstream flow fluctuations, regular diurnal fluctuations, or even have a stabilizing effect on the downstream flow regime. The deep reservoirs are thermally stratified during the summer, with a warm surface layer and a cold bottom layer. Depending on the location of the reservoir outlet, downstream water may either be warmer, colder, or approximately normal. Furthermore, in eutrophic reservoirs with bottom water outlets, the water oxygen concentration may be low. Changes in the flow regime and water temperature may detrimentally affect the downstream aquatic communities; to quote Casado et al. (1989), there is "a reduction of macrophytes, a reduction in faunistic richness both of fish and invertebrates, and a reduction of fish biomass, density and growth".

During the last 10-15 years there has been a growing public opinion against the construction of dams and reservoirs. For example, in *Norway*, the Lapp population protested against the damming of the river *Alta*, and in *Spain*, a 101 m high dam built on the river *Esla* in 1970 to form the Riano reservoir remains unused because the inhabitants of the valley to be expropriated have refused to move (García de Jalón, 1987). A more recent example is the construction of the Gabcikova hydroelectric power plant on the *Danube*; although both *Hungary* and the former *Czechoslovakia* were jointly involved in the original project, environmental groups in *Hungary* forced the Hungarian Government to withdraw.

Gabcikova hydroelectric power plant on the Danube.
Photo: Malis-Liaison/NORDFOTO

River channelization

The objective when modifying the course of a river is to improve certain features, for example flood control, drainage of the surrounding land, navigation, erosion prevention etc. River channelization comprises a number of physical measures, each of which is related to hydrological parameters; hence straightening changes the slope, dredging changes the depth and width, and dredging and weed cutting change the roughness. Other more radical methods of river channelization are culverting, lining, and piping.

In countries with an intensive agricultural production, many of the rivers have been regulated. In *Denmark*, for example, 85-98 per cent of the total river network has been regulated to some extent (Brookes, 1987; Iversen et al. 1993).

Physical effects

Channelization has great impact on a river because it disrupts the existing physical equilibrium of the watercourse; to compensate for the alteration in one or more of the hydraulic parameters, and to establish a new, stable equilibrium, other parameters will change. Because straightening of a river increases its slope, the energy in the moving water has to be dispersed over a smaller surface; as a result the water is able to move larger particles and sediment discharge increases through bank erosion. If the river is not repeatedly manipulated or stabilized by culverting, lining, etc., this will eventually lead to widening of the river channel and to a subsequent reduction in water velocity. River channelization generally changes a heterogeneous system into a homogeneous system. The flow becomes uniform, pools are lost and the substrate becomes uniform throughout the channel (*Figure 12*).

Channelization can also have great impact on the riparian vegetation; trees are often logged to allow channel maintenance by machines and shrubs are cut to ensure sufficient drainage. This increases solar radiation at the stream surface, thereby increasing the water temperature, reducing the concentration of dissolved oxygen, and increasing the instream primary production. In nutrient-rich watercourses this results in enhanced growth of benthic phytoplankton, filamentous algae, or macrophytes.

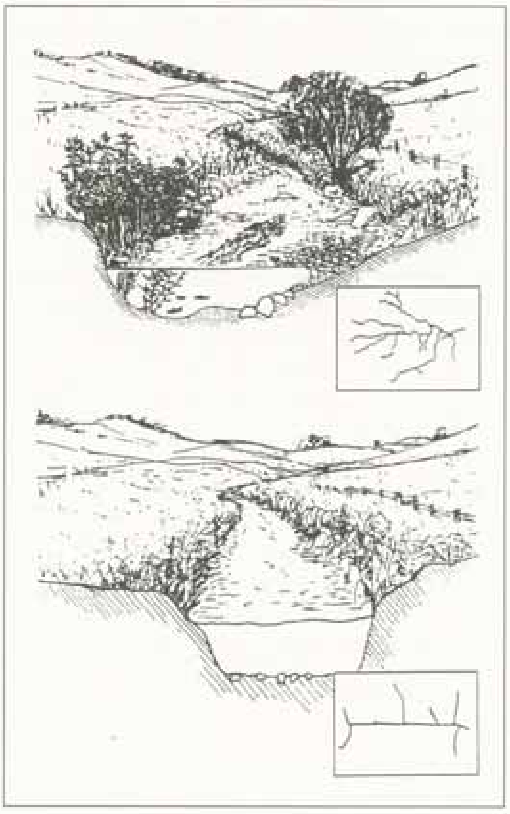


Figure 12:
The difference in physical variation in a natural and a channelized watercourse. Insert shows typical drainage patterns.

Photo: Palle Uhd Jepsen/BIOFOTO

Another effect of the channelization of rivers and drainage of wetlands may be increased nutrient and organic matter loading of rivers and the marine environment. While the annual nitrogen removal capacity of wetlands and natural rivers can be as much as several hundred kg N per hectare, that of channelized rivers and drained wetlands is significantly reduced. Naturally riparian zones alongside meandering rivers therefore play an important role in balancing intensive agricultural and ecological interests.

Biological effects

The velocity of river water is one of the major factors regulating the structure of riverine plant and animal communities (Brookes, 1988; Westlake, 1973). The uniform and often unstable sediment found in channelized watercourses is suitable for few, if any, plant species. Furthermore, as the uniform water flow precludes areas with little or no flow, resting sites for fish and invertebrates are virtually absent. The general effect of channelization is therefore a reduction in habitat number and diversity and a consequent reduction in species number and diversity. Similarly, the biomass and production of fish and invertebrates is usually lower in channelized watercourses, as illustrated in *Figure 13*.

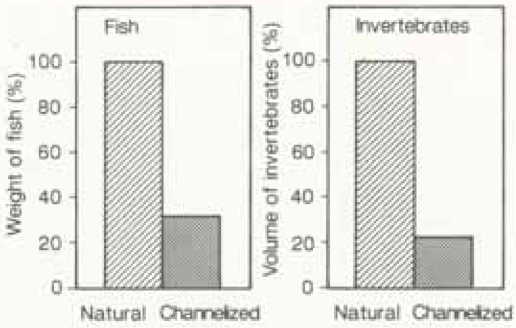


Figure 13:
Difference in the amount of fish and invertebrates in natural and channelized watercourses. (Adapted from Brookes, 1988).

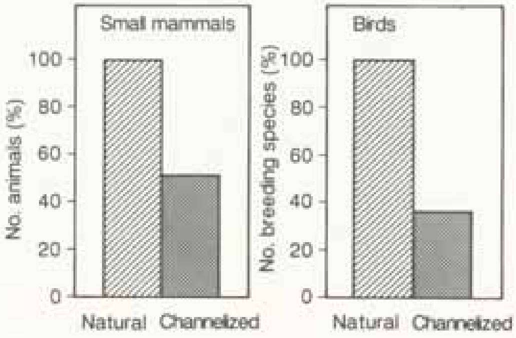


Figure 14:
Difference in number of small mammals and birds alongside natural and channelized watercourses. (Adapted from Brookes, 1988)

The riparian zones are also affected by channelization. Thus animal species foraging and/or breeding on the banks decline in number (*Figure 14*). In addition, a number of plant species that are confined to the more or less water-saturated soil adjacent to the river are also affected. The overall result is a reduced diversity of the riparian zones.

Organic pollution of rivers

Organic matter derived from diverse human activities is a major source of pollutant discharge to rivers. The decomposition and break down of organic matter is mediated by microorganisms and mainly takes place at the surface of the sediment and vegetation in smaller rivers, and in the water column in larger rivers. As the process requires the consumption of oxygen, severe organic pollution may lead to rapid deoxygenation of the river water and hence to the disappearance of fish and aquatic invertebrates; the invertebrate community then becomes uniform with only a few robust species able to tolerate the low oxygen concentration. Decomposition of organic waste also results in the release of ammonium; although not in itself toxic, it may, depending on the pH and temperature of the water, be converted to ammonia, which is poisonous to fish.

The most important sources of the organic waste load of rivers are cities and agriculture. Immediately downstream of a sewage effluent organic matter decomposition reduces the oxygen content of the water and results in an increase in ammonium (*Figure 15*). Further downstream the concentration of organic matter decreases as a result of dilution and decomposition. As the distance from the effluent increases, bacteria oxidize the ammonium to nitrate, and oxygen enters the water via the water surface, thereby increasing its oxygen content. Eventually the levels of organic matter, oxygen, and ammonium reach those present immediately upstream of the sewage effluent, the process of recovery being called *self-purification*. An example is the *Danube*, which is already polluted by organic matter when it enters *Hungary*. As it winds its way through the country the river receives large amounts of organic matter from tributaries and cities, especially from Budapest; however, by the time it leaves the country and enters *Croatia*, an amount of organic matter equal to that discharged in *Hungary* has been decomposed (Varga et al. 1990; Benedek & Major, 1992). This does not imply that rivers can take up an unlimited amount of organic matter without suffering; the pollution may be so severe that the self-purification capacity is insufficient. Thus the *Danube* is still polluted when it leaves *Hungary*, and the *Rhine* was polluted with such excessive amounts of organic matter between World War II and the early 1970s that there was such serious oxygen depletion in the central and lower courses that the river was virtually dead (Friedrich & Müller, 1984).

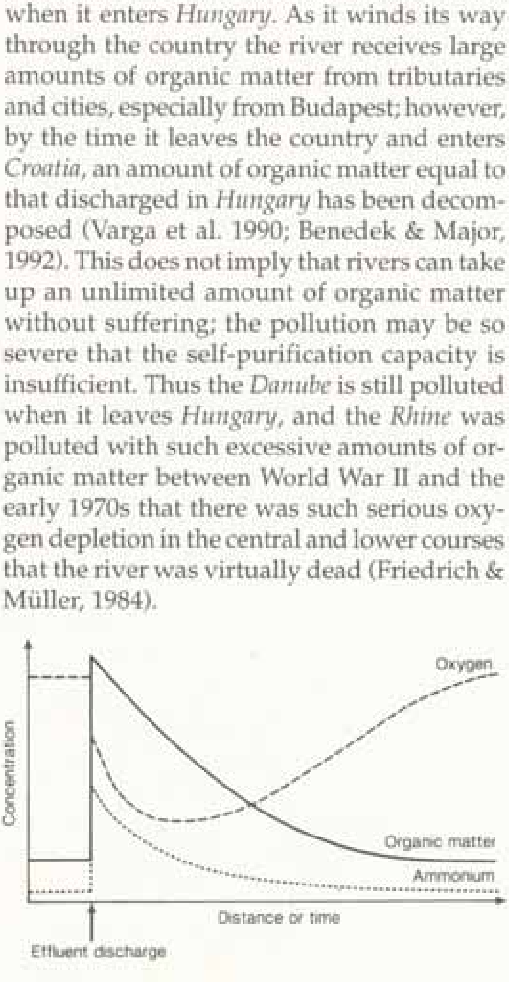


Figure 15:
Impact of an organic matter effluent on river concentrations of organic matter, oxygen, and ammonium.

Organic matter content

Since decomposition of organic matter requires oxygen, the amount of organic matter in a river can be measured in terms of the Biochemical Oxygen Demand (BOD) or the Chemical Oxygen Demand (COD), the units of which are mg O_2 l^{-1}. River reaches little affected by human activities generally have a BOD below 2 mg O_2 l^{-1} whereas a BOD exceeding 5 mg O_2 l^{-1} generally indicates pollution. In large rivers suffering from severe eutrophication elevated BOD values can occur due to decomposition of phytoplankton: in this case, high BOD values are not necessarily indicative of organic pollution. Measurement of BOD is the most widespread method in Europe, but many countries also measure COD, and some only use COD. Although both BOD and COD indicate the potential oxygen demand of the organic matter in the water, there is not necessarily a correlation between the two measurements.

BOD, COD, and oxygen content data from a large number of river stations in 33 European countries is collated in *Table 7*. Median BOD, COD, and oxygen is 2.8; 14.5; and 9.7 mg O_2 l^{-1}, respectively. As can be seen, annual mean BOD was below 5 mg O_2 l^{-1} and the oxygen content above 8 mg O_2 l^{-1} at more than 75 per cent of the river stations. Extremely high BOD is generally only seen in smaller rivers polluted with raw sewage or animal slurry, a BOD exceeding 500 mg O_2 l^{-1} then being possible.

Table 7:

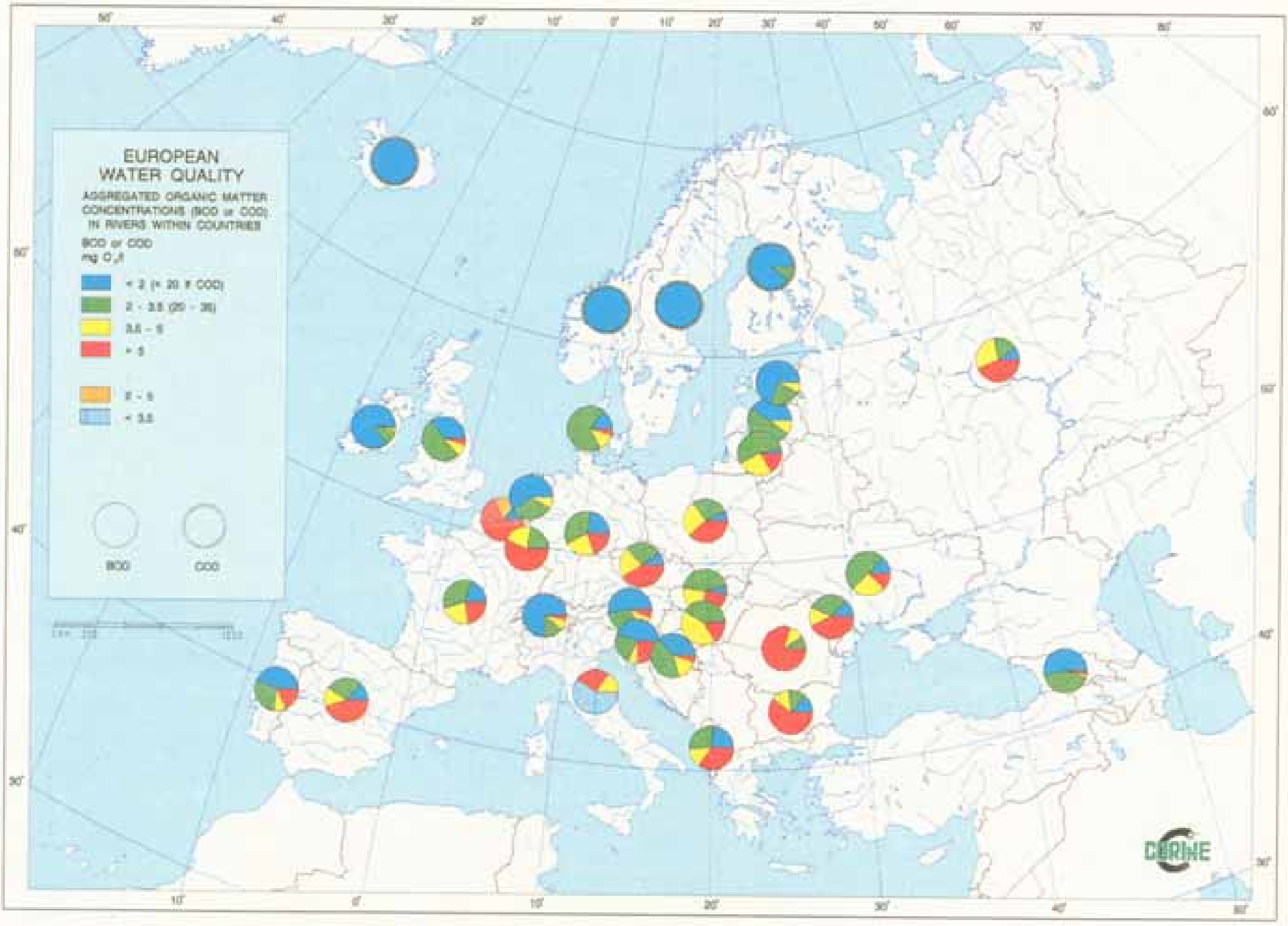
Descriptive statistics for annual mean organic matter and oxygen in European rivers.

	Number of river stations	Percentage of river stations with concentrations not exceeding (mg O_2 l^{-1})						
		Mean	10%	25%	50%	75%	90%
All rivers							
BOD	645	4.5	1.4	1.9	2.8	4.6	7.9
COD	470	18.5	4.5	7.7	14.5	24.6	36.6
Oxygen	620	9.4	6.4	8.4	9.7	10.7	11.6
Near pristine rivers							
BOD	11			1.2	1.6	2.7	
COD	23			5.1	13.3	29.9	
Oxygen	8			10.2	10.6	11.1	

Figure 16:

Frequency distribution of annual mean concentrations of organic matter in rivers.

(Data compiled by NERI and EEA-TF for this report. Belgium: only the Flandern part. ATU method used in the United Kingdom).



The information obtained from 33 European countries concerning the percentage of rivers with BOD or COD levels in specified classes is summarized in *Figure 16* and the BOD and COD concentrations of a large number of European rivers is presented in *Figure 17*.

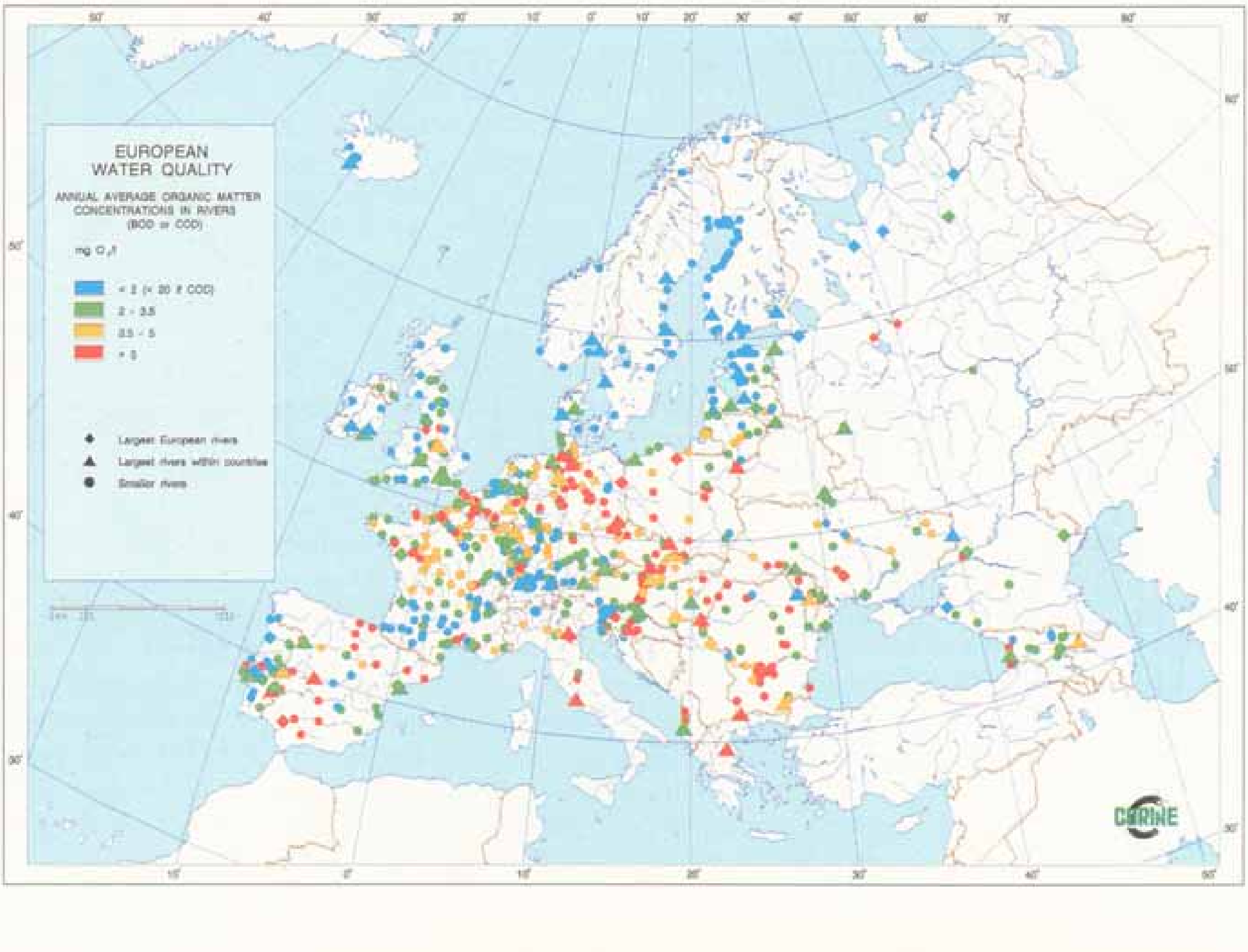
In *Iceland, Norway, Sweden*, and *Finland* the organic matter content is only measured as COD. In these countries riverine discharge of organic waste derived from human activity is generally negligible and COD-levels therefore generally low (*Figure 16*). In terms of BOD, rivers in *Ireland, Georgia, Estonia, The Netherlands, Switzerland, Austria, Latvia, the United Kingdom, Denmark*, and *Croatia* are least affected, less than 25 per cent of the rivers having a BOD exceeding 3.5 mg O_2 l^{-1}. In *Hungary, Lithuania, Portugal, France, the Ukraine, Germany, Slovenia*, and *Italy* the rivers are moderately affected, less than 25 per cent having a BOD exceeding 5 mg O_2 l^{-1}. More affected rivers are found in *the Slovak Republic, Albania, Poland, the Czech Republic, Moldova, the Russian Federation, Spain*, and *Luxembourg*, where more than 25 per cent of the rivers have a BOD exceeding 5 mg O_2 l^{-1}. BOD is highest in *Bulgaria, Belgian Flanders*, and *Romania*, exceeding 5 mg O_2 l^{-1} in 60, 69, and 80 per cent of the rivers, respectively.

Human activities and organic matter

The naturally occurring organic matter in small rivers mainly originates from the terrestrial environment as dissolved organic matter or as large particles such as leaves, twigs, etc. Generally, this organic matter decomposes slowly. In contrast, organic matter in waste water is generally fine particulate and decomposes rapidly. The discharge of organic waste water therefore results in a marked and abrupt increase in oxygen consumption in the river.

The level of organic matter in the rivers generally increases with population density in the catchments, and the oxygen content decreases (*Figure 18*). Thus whereas BOD-con-

Figure 17:
Annual mean BOD-levels at specific river stations in European rivers.
(Data compiled by NERI and the EEA-TF for this report. ATU method used in the United Kingdom.)



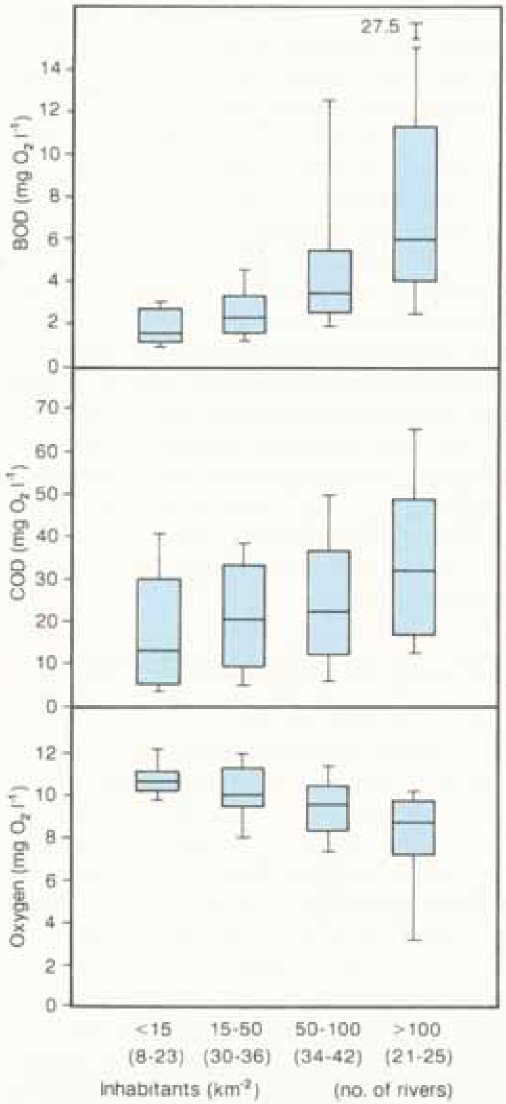


Figure 18:
Relationship between population density in more than 100 European river catchments and the annual mean BOD, COD, and oxygen levels.
Median, upper and lower quartiles, and 10 and 90 percentiles are shown.

centration is lower than 2 mg O_2 l^{-1} in catchments with less than 15 inhabitants km^{-2}, it generally exceeds 5 mg O_2 l^{-1} in catchments with more than 100 inhabitants km^{-2}. The great variation found in densely populated areas is mainly attributable to variations in the extent of waste water treatment. Well-functioning treatment plants are able to decompose up to 90 per cent of the organic matter in the waste water.

Assessment of river quality

In most European countries the environmental state of the rivers has been monitored for many years. However, as pollution has both physico-chemical and biological effects on the receiving water, the quality of the water can be assessed in many different ways. Numerous methods are therefore in use throughout Europe. The definition of river quality used in this chapter is given in *Box 5*.

The quality of European rivers is summarized in *Table 8*. That of about a quarter of the river reaches is classified as poor or bad. However, most of the countries classify the quality of 50 per cent or more of their river reaches as good or fair. *Iceland, Scotland, Ireland,* and *Northern Ireland* have the highest proportion of rivers classified as good quality while *England/Wales, Finland, the former West Germany, Croatia, Austria, Latvia, the Russian Federation,* and *Lithuania* classify the quality of more than 75 per cent of their rivers as good or fair. More than 25 per cent of the rivers have poor or bad quality in *Luxembourg, Romania, the Czech Republic, Slovenia, Poland, Bulgaria, Italy, Denmark,* and *The Netherlands*. Furthermore, the percentage of river reaches classified as having bad quality is highest in *the Czech Republic* and *Poland* (28 per cent) and in the *Belgian Flanders* (37 per cent).

Box 5:
River quality classification.

Good quality
River reaches with nutrient-poor water, low levels of organic matter; saturated with dissolved oxygen; rich invertebrate fauna; suitable spawning ground for salmonid fish.

Fair quality
River reaches with moderate organic pollution and nutrient content; good oxygen conditions; rich flora and fauna; large fish population.

Poor quality
River reaches with heavy organic pollution; oxygen concentration usually low; sediment locally anaerobic; occasional mass occurence of organisms insensitive to oxygen depletion; small or absent fish population; periodic fish kill.

Bad quality
River reaches with excessive organic pollution: prolonged periods of very low oxygen concentration or total deoxygenation; anaerobic sediment, severe toxic input; devoid of fish.

Table 8:

Percentage of river reaches in various European countries classified as being of good, fair, poor, or bad quality (for definitions see *Box 5*).

In a number of cases national data have been classified by NERI to fit into the present classification scheme.

	River quality (%)			
	Good	Fair	Poor	Bad
Austria 1991[1]	14	82	3	1
Belgian Flanders 1989-90[2]	17	31	15	37
Bulgaria 1991[1]	25	33	31	11
Croatia[1]	15	60	15	10
Czech republic 1990[3]	12	33	27	28
Denmark 1989-91[4]	4	49	35	12
England/Wales 1990[8, 9]	64	25	9	2
Finland 1989-90[1]	45	52	3	0
Germany 1985[5]	44	40	14	2
Iceland[1]	99	1	0	0
Ireland 1987-90[6]	77	12	10	1
Italy[7]	27	31	34	8
Latvia[1]	10	70	15	5
Lithuania[1]	2	97	1	0
Luxembourg[1]	53	19	17	11
Netherlands 1990[1]	5	50	40	5
Northern Ireland 1990[8]	72	24	4	0
Poland 1990[1]	10	33	29	28
Romania[1]	31	40	24	5
Russian Federation[1]	6	87	5	2
Scotland 1990[8,10]	97	2	1	0
Slovenia 1990[1]	12	60	27	1

Data from: [1]Questionnaires ; [2]Vlaamse Milieumaatschappij, 1991; [3]Kinkor, 1992; [4]Danish Ministry of the Environment, 1992; [5]Toner, 1987 (Former West Germany only); [6]Clabby et al. 1992; [7]De Pauw et al. 1992; [8]Department of the Environment (UK), 1992; [9]National Rivers Authority, 1991; [10]Scottish Office, Environment Department, 1992.

The greater the amount of organic matter present in river water, the lower the oxygen concentration, and the higher the ammonium concentration. These two relationships are illustrated in *Figure 19* using data from 482 and 365 river stations, respectively. A low oxygen concentration influences the river fauna. Maintainance of a salmon or trout population in a river requires a minimum oxygen concentration of 6 mg O_2 l^{-1} is necessary (EEC Directive 78/659 no. L 222 1) (*Figure 19A*). To reduce the risk of fish kill, the ammonium concentration should not exceed 1 mg N l^{-1} (*Figure 19B*). Although ammonium is not in itself toxic to fish, it becomes toxic when converted to ammonia. Thus if the ammonia concentration exceeds 0.025 mg l^{-1}, trout growth is prevented, and if it exceeds 0.25 mg l^{-1}, the trout die. Rivers with large sewage discharges exceed these limits.

Trends in organic matter discharge to rivers

After World War II riverine discharge of organic waste increased in many European countries with resultant severe oxygen depletion. During the last 15-20 years, however, biological treatment of domestic and industrial waste waters has intensified, and organic matter loading of rivers has consequently decreased in many parts of Europe, the result being that many rivers are now fairly well oxygenated.

Photo: Jan K. Winther/BIOFOTO

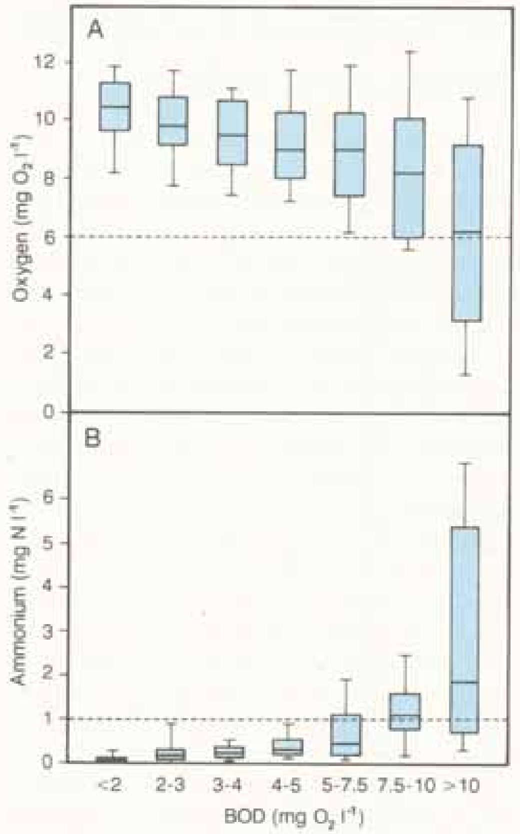


Figure 19:
Relationship between annual mean BOD-levels and:
A: annual mean oxygen concentration;
B: annual mean ammonium concentration.
The minimum oxygen and maximum ammonium concentrations for trout and salmon are shown as a broken line (EEC Directive 789/659 no. L 222 1).

An example is the river *Rhine*. Rebuilding of industry after World War II led to high loads of poorly treated or untreated sewage being discharged into the river. This caused the oxygen contents to fall considerably (*Figure 20*), and long stretches became biologically devastated. In the 1960s the deterioration in river quality became so apparent that countermeasures such as increasing the number of sewage treatment plants were implemented. In the eight year period from 1973-81, the percentage of sewage water that was treated before being discharged into the *Rhine* rose from about 30 to 80-90 per cent (Dijkzeul, 1982 in Wolff, 1987). The marked reduction in organic pollution led to a clear improvement in water oxygen content and the return of several of the animal species that had disappeared. Thus, although the general pollution of the *Rhine* is still considerable, there are signs that conditions are improving (eg. Admiraal et al. 1993).

A comparison of BOD-levels at 223 river stations throughout Europe reveals signs of improving conditions as well. From the period 1977-82 to 1988-90 the organic matter concentration decreased at almost 75 per cent of the river stations (*Figure 21*), the reduction being greater than 25 per cent at almost half of the

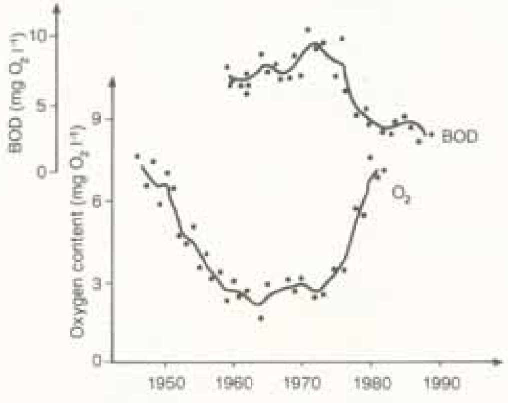


Figure 20:
BOD and minimum oxygen content in the Rhine at the German/Dutch border.
(Modified from: RIWA, 1983 (in Friedrich & Müller, 1984); Umweltbundesamt, 1992).

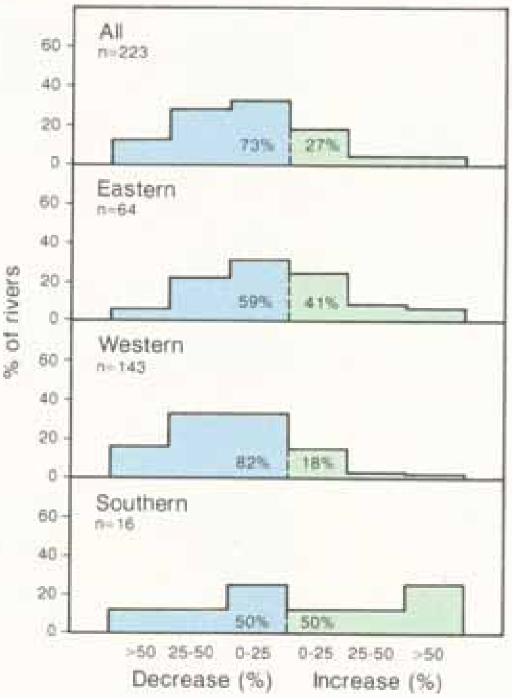


Figure 21:
Percentage of river stations (N=223) in which annual mean BOD-concentration decreased or increased by the ranges shown between the periods 1977-82 and 1988-90.

stations. An increase of more than 25 per cent was seen at 8 per cent of the river stations.

The improvement was greatest in western Europe, primarily as a result of intensified waste water treatment. About half of the river stations show a decrease in organic matter concentration of more than 25 per cent. The improvement was less pronounced in eastern Europe, where about 30 per cent of the river stations had a decrease of more than 25 per cent but about 15 per cent had an increase of more than 25 per cent (*Figure 21*). The reduction in industrial production seen recently in many eastern European countries, may have lead to decreased organic matter loading. There is apparently no overall reduction in southern Europe, but the number of rivers included is too small for firm conclusions.

Organic pollution is still a serious problem in many European rivers, and will continue to be so for as long as large amounts of sewage water are discharged into the rivers without being treated. Countries presently experiencing industrial depression should be especially attentive to this problem and develop their sewage plant capacity as their industrial production can be expected to increase in the future.

Nutrients in European rivers and lakes

Precipitation that falls on the surface of the land dissolves and absorbs minerals as it drains through the soil. In pristine areas, the chemical composition of river and lake water is mainly determined by that of the soil and underlying bedrock. Nutrient levels in such waters are generally low.

Human settlement and associated clearance of forest, agricultural development, and urbanization greatly accelerate the run-off of materials and nutrients into rivers and lakes. In lakes this stimulates the growth of phytoplankton and other aquatic plants and, in turn, that of organisms higher up the aquatic food chain. The process is usually known as "cultural eutrophication". Enhanced biological production and other associated effects of eutrophication are generally more apparent in lakes, reservoirs, coastal areas, and large, slowly flowing rivers, than in small rivers. Although phosphorus tends to be the nutrient that most frequently limits plant growth in lakes and reservoirs, increased nitrogen levels can also lead to higher biological production

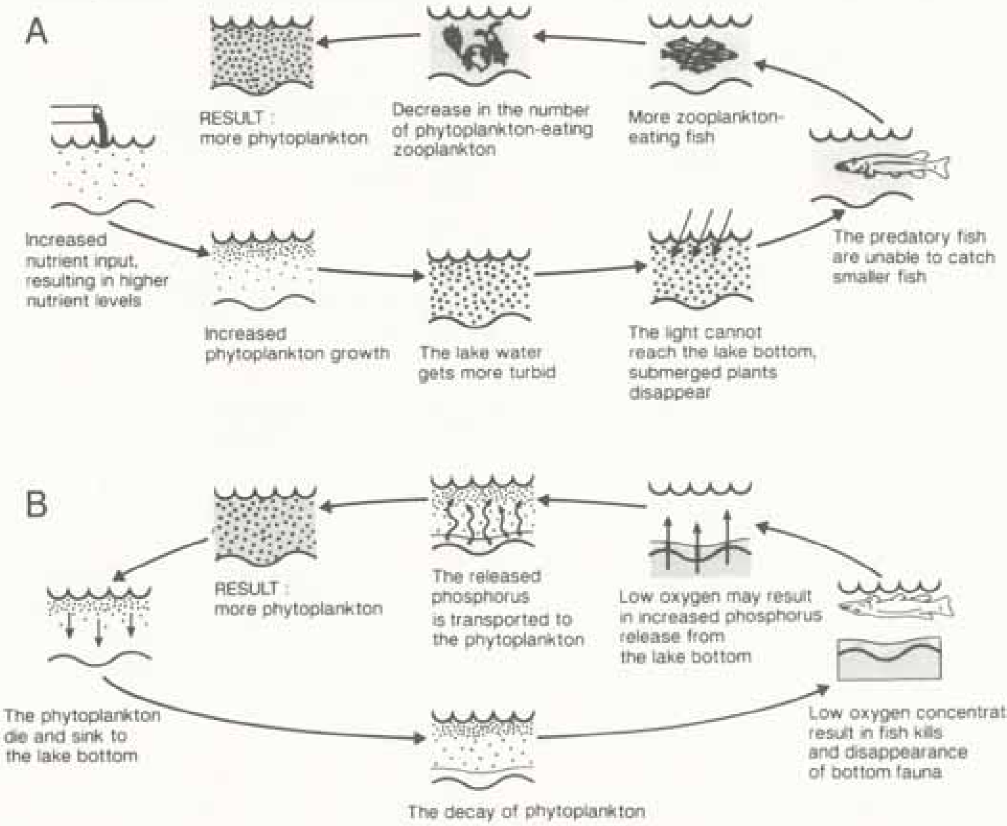


Figure 22: Schematic representation of the ecological effects of eutrophication.

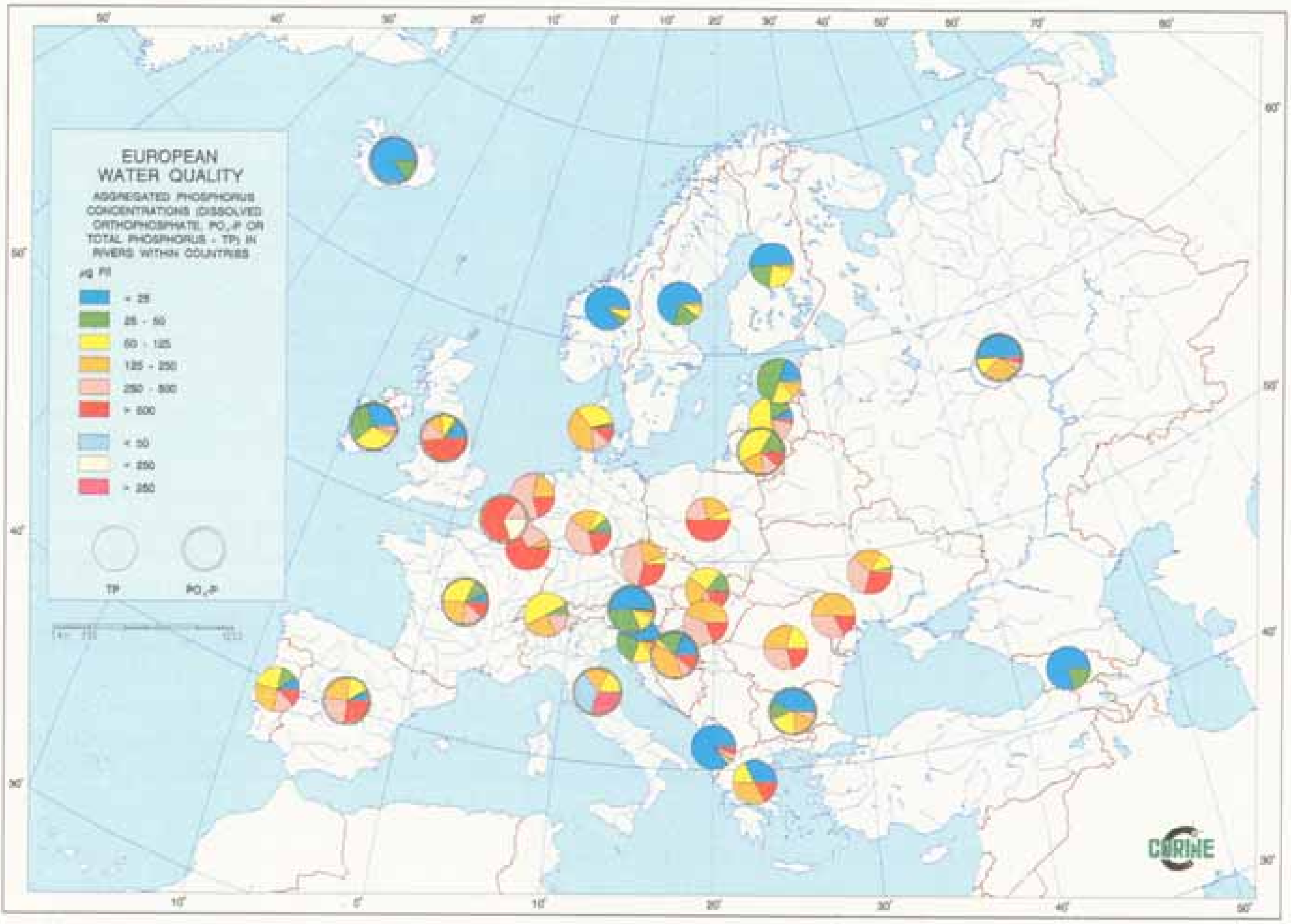


Figure 23: Frequency distribution of annual mean phosphorus concentration in the rivers of different European countries. (Data compiled by NERI and EEA-TF for this report.)

(OECD, 1982), especially in marine areas, where it is usually the nutrient that most frequently limits plant growth.

The ecological consequences of cultural eutrophication can be significant. High nutrient input to standing waters may provoke a shift in the biological structure (*Figure 22*); clearwater shallow lakes with submerged plants become dominated by phytoplankton, and the water therefore becomes so turbid that the submerged plants disappear. In addition, excessive growth of blue-green algae may sometimes occur, leading to the formation of surface scum and the production of toxins potentially poisonous to fish, cattle, dogs, and man. The fish community also changes and becomes dominated by species more tolerant to the turbid environment (*Figure 22*).

When the phytoplankton sink to the lake bottom their decomposition may reduce the oxygen concentration in the water to levels too low to support fish and benthic invertebrates, the result being fish kill and the disappearance of benthic invertebrates. Low oxygen levels may also enhance the release of phosphorus from the lake sediment, thereby further enhancing phytoplankton production (*Figure 22*).

Excessive phytoplankton growth is easy to detect and it significantly affects both the use and the aesthetic quality of the lake. In cases where lake water is used for domestic water supply, eutrophication leads to taste and odour problems, and necessitates treatment and filtration of the water prior to use; this is an expensive and time-consuming process, especially in the case of very eutrophic water.

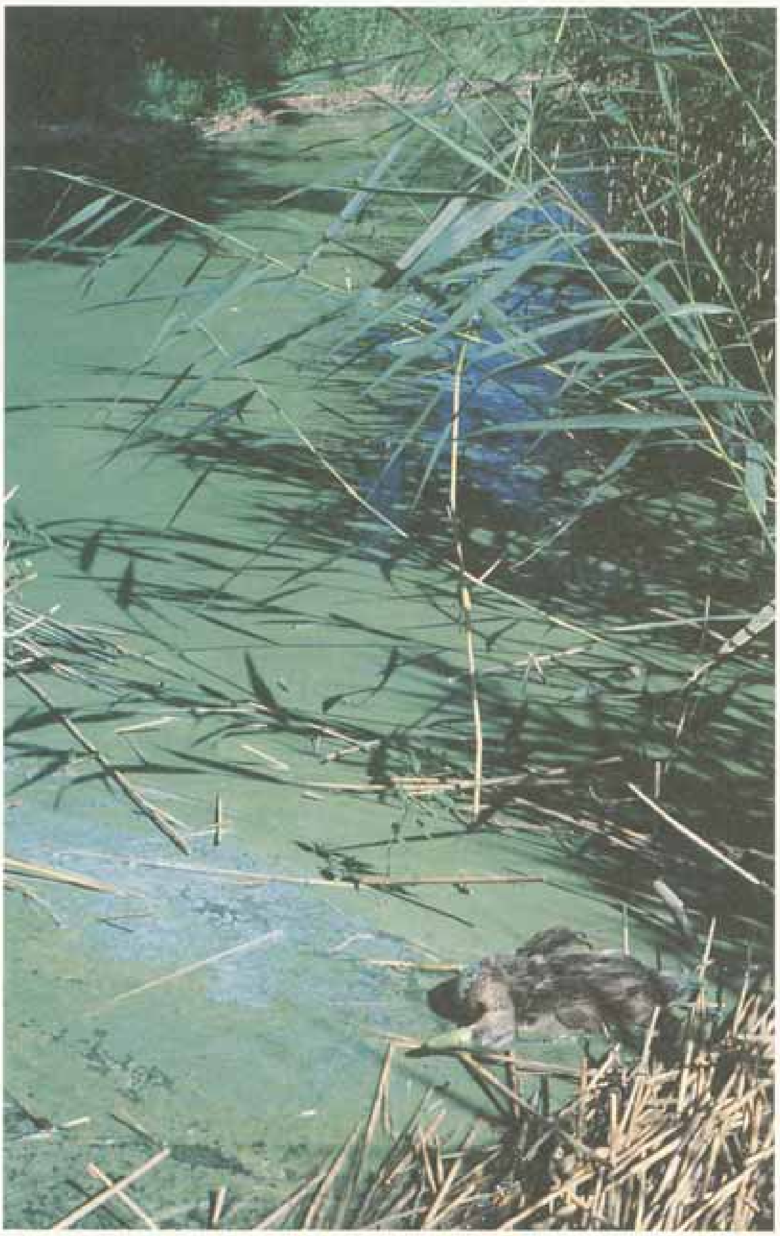


Photo: Jens M. Andersen

Table 9:
Descriptive statistics of annual mean phosphorus concentration in European rivers.

	Number of river stations		Percentage of river stations with concentrations not exceeding (µg P l^{-1})				
		Mean	10%	25%	50%	75%	90%
All rivers							
Total phosphorus	546	279	17	59	173	369	590
Dissolved phosphate	412	330	15	45	126	287	778
Near pristine rivers							
Total phosphorus	39	26		8	12	30	

Nutrient concentrations in rivers

Phosphorus in rivers

Phosphorus is measured both as total phosphorus and as dissolved orthophosphate. In 321 European rivers dissolved orthophosphate was found to average 59 per cent of total phosphorus. In some countries total phosphorus is not measured and data is only available for dissolved orthophosphate. In such cases the data has not been converted to total phosphorus, but is presented as dissolved phosphate and the fact noted in the figures and tables.

Information concerning annual mean phosphorus concentrations at 546 river stations in 34 countries is collated in *Table 9*. Median annual mean total phosphorus and dissolved phosphate were found to be 173 and 126 µg P l^{-1}, respectively, annual mean phosphorus levels being below 50 µg P l^{-1} at only 25 per cent of the stations. In catchments with little or no human activity phosphorus levels in rivers are generally lower than 25 µg P l^{-1}. Phosphorus levels exceeding 50 µg P l^{-1} indicate an anthropogenic influence such as sewage effluent and agricultural run-off. In rivers heavily polluted by sewage effluent, phosphorus levels may exceed 1000 µg P l^{-1}.

The frequency distribution of phosphorus levels in rivers has been compiled for 34 European countries, each country having supplied information about the percentage of rivers with annual mean phosphorus levels in the following classes: below 25 µg P l^{-1}, 25-50 µg P l^{-1}, 50-125 µg P l^{-1}, etc. (*Figure 23*). This provides an overview of the percentage of rivers with low and high phosphorus levels. The phosphorus level at a large number of specific European river stations is presented in *Figure 24* as well.

The lowest phosphorus levels are found in the rivers in *Norway* and *Iceland*. Although many rivers in *Sweden, Finland, Ireland, the Russian Federation, Slovenia, Albania,* and *Bulgaria* also have a low annual mean phosphorus concentration (*Figure 23*), the concentration exceeds 50 µg P l^{-1} in 10-40 per cent of the rivers in *Sweden, Finland* and *Ireland*, and exceeds 125 µg P l^{-1} in 10-40 per cent of the rivers in *the Russian Federation, Slovenia,* and *Bulgaria*.

In many other countries only 10-20 per cent of the rivers have a phosphorus concentration below 50 µg P l^{-1}. These relatively unpolluted rivers are generally situated in catchments in

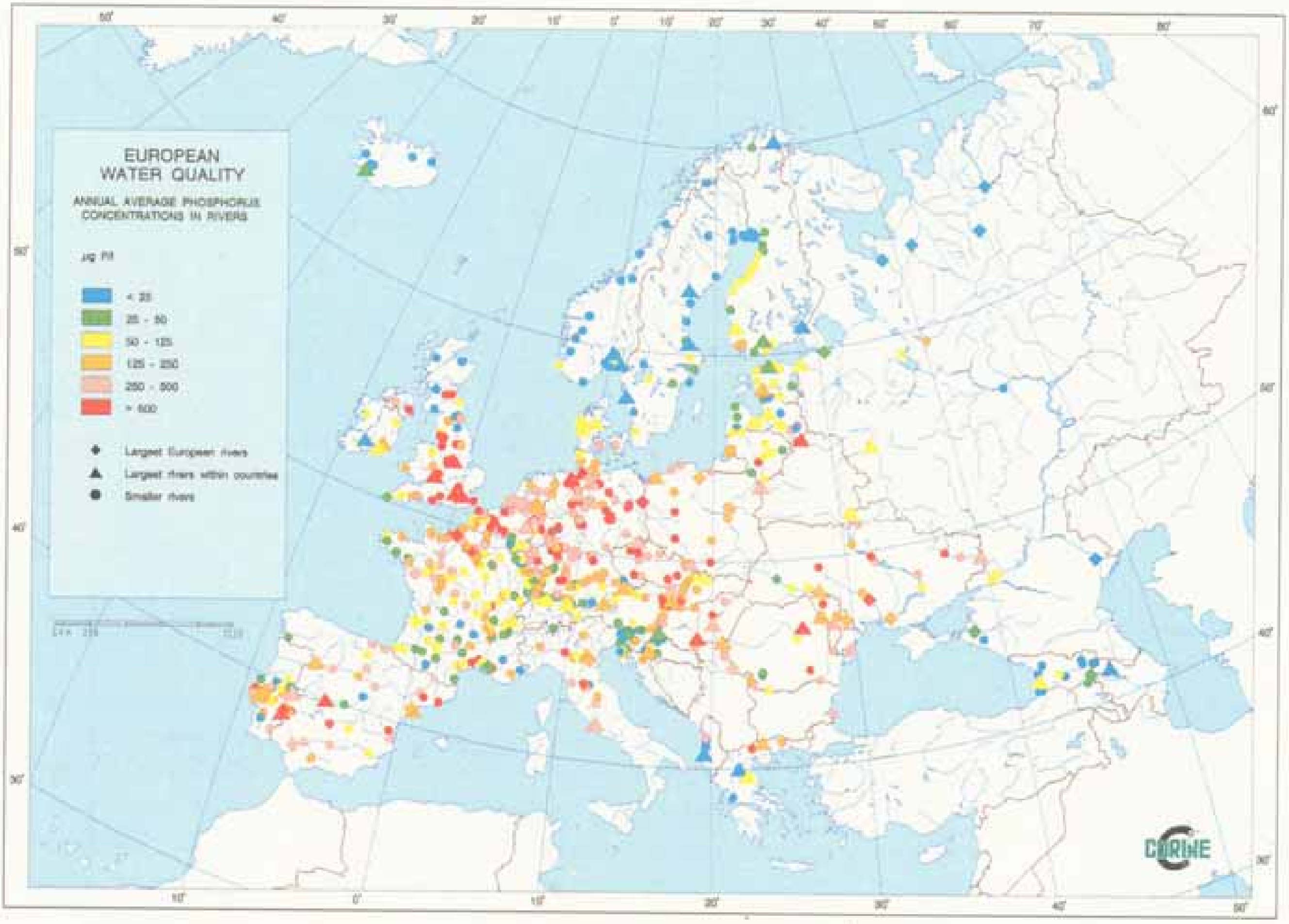


Figure 24:
Annual mean phosphorus concentration in specific European rivers.
(Data compiled by NERI and EEA-TF for this report.)

mountainous and forested regions where the population density is low. In *Estonia, Latvia, Lithuania, Switzerland, Austria, Croatia, Italy,* and *Portugal*, more than 40 per cent of the rivers have a phosphorus level below 125 µg P l^{-1}; however, many of the rivers in these countries have a high phosphorus level.

The highest phosphorus levels are found in a band stretching from southern *England*, across the central part of Europe through *Romania* and *Moldova* to *the Ukraine*; in these countries more than 80 per cent of the rivers usually have a phosphorus concentration exceeding 125 µg P l^{-1}. In *Poland, Belgian Flanders,* and *the United Kingdom*, more than 50 per cent of the rivers even have a phosphorus level exceeding 500 µg P l^{-1}.

With the exception of large rivers in *the Russian Federation* and the Nordic countries, the phosphorus levels generally exceed 100 µg P l^{-1} in the downstream reaches in all of the largest rivers in Europe (*Figure 24*).

Bearing in mind the regional differences described above, Europe can be divided in four main regions, the river phosphorus levels of which are shown in *Figure 25*. The phosphorus levels are lowest in the Nordic countries, medium in both the southern and eastern European countries (although slightly lower in southern European rivers), and highest in the western European countries.

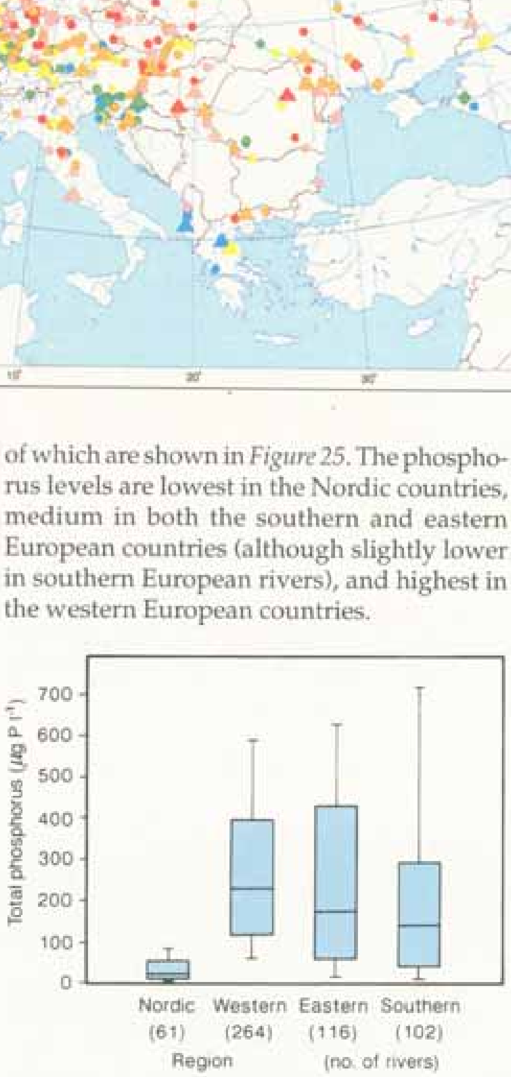


Figure 25:
Annual mean total phosphorus levels in rivers in four European regions. Median, upper and lower quartiles, and 10 and 90 percentiles are shown.

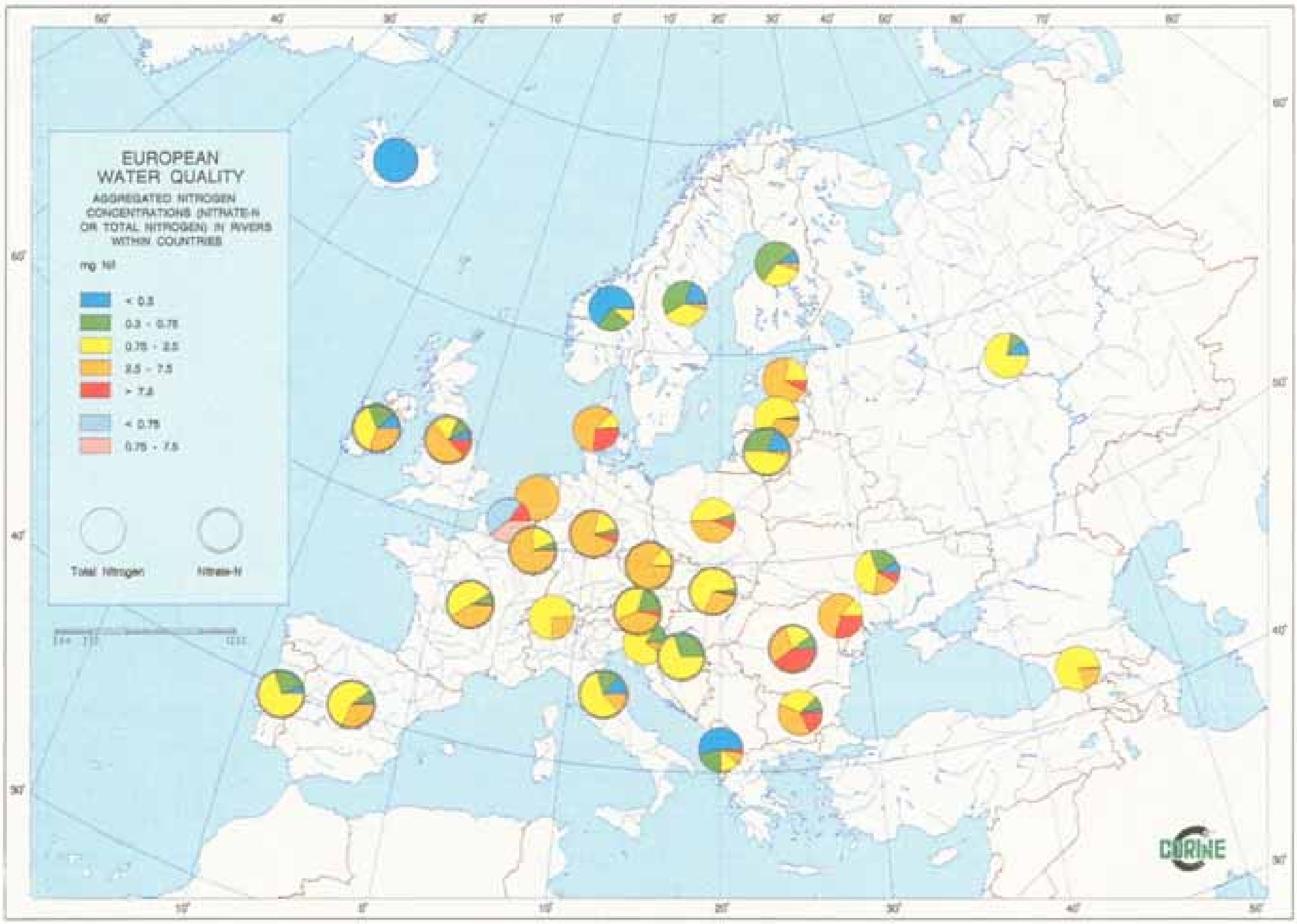


Figure 26:
Frequency distribution of annual mean nitrogen concentration in the rivers of European countries.
(Data compiled by NERI and EEA-TF for this report.)

Nitrogen in rivers

Dissolved inorganic nitrogen, particularly nitrate and ammonium, constitutes most of the total nitrogen in river water; thus inorganic nitrogen was found to constitute 88 per cent of the total nitrogen in 400 European rivers, nitrate being the dominant part (78 per cent). In some countries data is only available for nitrate and occasionally ammonium. The results presented in this chapter are therefore either total nitrogen, inorganic nitrogen, or only nitrate nitrogen, as indicated in the figures and tables.

Annual mean nitrogen concentration at 650 river stations in 34 countries is summarized in *Table 10*. Whereas ammonium levels are generally below 0.5 mg N l^{-1}, nitrate and total nitrogen concentrations exceed 1 mg N l^{-1} in most of the rivers. The average level of ammonium and nitrate in pristine rivers is reported to be 0.015 mg N l^{-1}, and 0.1 mg N l^{-1}, respectively (Meybeck, 1982). Although rivers in a strictly pristine state are rarely found in Europe because of high atmospheric nitrogen deposition, the levels of nitrogen in relatively unpolluted streams ranged from 0.1 to 0.5 mg N l^{-1} (*Table 10*). Nitrogen levels exceeding 1 mg N l^{-1} indicate an anthropogenic influence eg. agricultural run-off and sewage effluent. The ammonium level normally rises when rivers receive sewage effluent or effluent from animal husbandry farms; in heavily polluted rivers the ammonium level may rise to as much as 1-5 mg N l^{-1}.

Table 10:
Descriptive statistics of annual mean nitrogen concentration in European rivers.

	Number of river stations	**Percentage of river stations with concentrations not exceeding (mg N l^{-1})**					
		Mean	**10%**	**25%**	**50%**	**75%**	**90%**
All rivers							
Total nitrogen	329	3.07	0.30	0.80	2.12	4.50	7.07
Nitrate	654	2.63	0.25	0.70	1.80	3.90	5.72
Ammonium	580	0.67	0.03	0.07	0.18	0.45	1.42
Near pristine rivers							
Total nitrogen	43	0.40		0.19	0.33	0.39	
Nitrate	39	0.30		0.05	0.10	0.22	

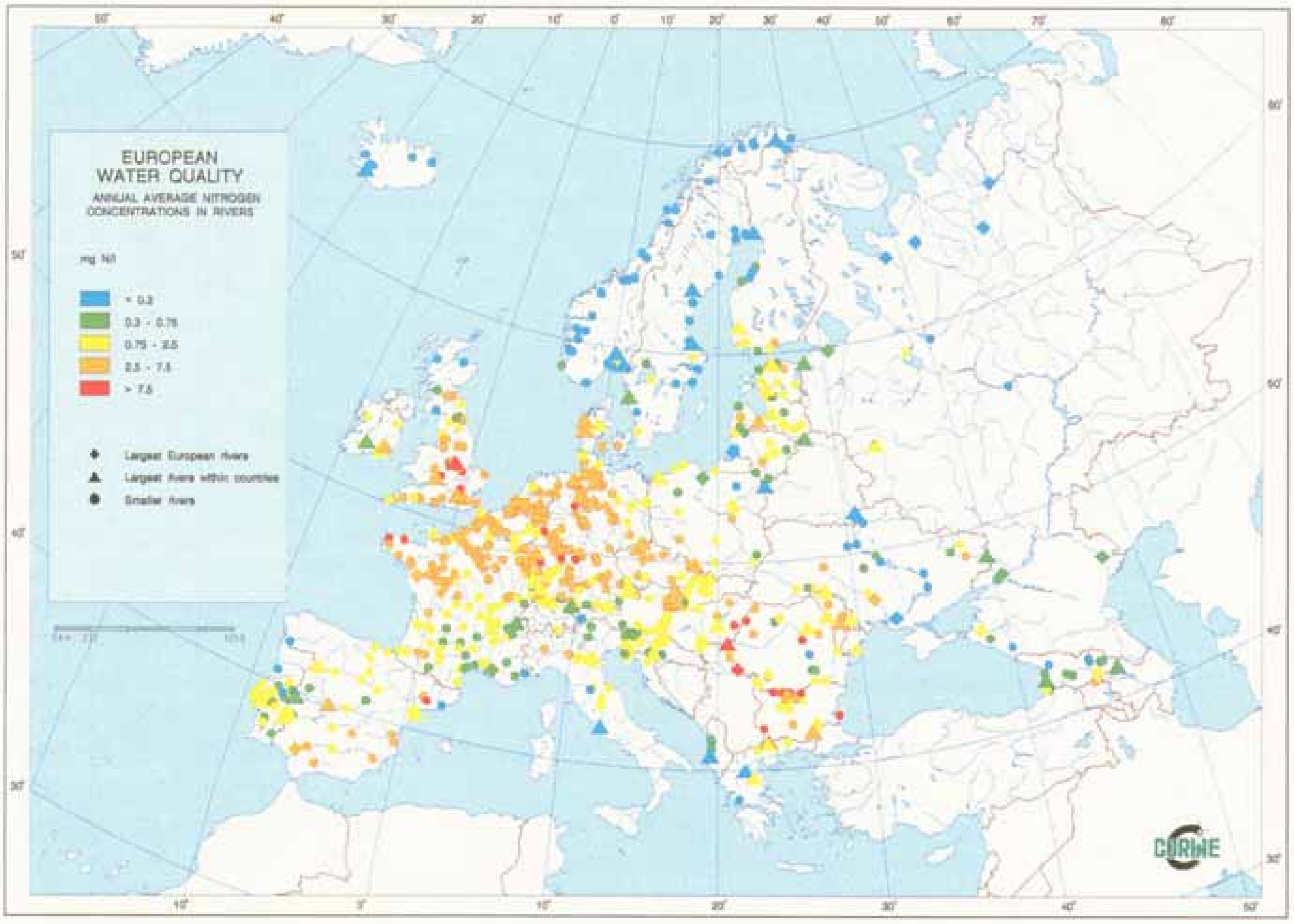


Figure 27: Annual mean nitrate concentration in specific European rivers. (Data compiled by NERI and EEA-TF for this report.)

The nitrogen concentration is generally lowest in rivers in *Iceland, Norway, Sweden, Finland*, and *Albania*, being below 0.75 mg N l^{-1} in 60-100 per cent of the rivers (*Figure 26*). In southern *Sweden* and *Finland*, and in *Latvia, Estonia, Lithuania, the Russian Federation, Ireland, France, Austria, Switzerland, Slovenia, Portugal*, and *Spain*, nitrogen concentrations are relatively higher, ranging from 1-3 mg N l^{-1} in the majority of the rivers (*Figures 26 & 27*).

The highest nitrogen levels are found in rivers, in *the United Kingdom, Denmark, Germany, The Netherlands, Belgian Flanders, Luxembourg, Poland, the Czech Republic, Romania, Bulgaria*, and *Moldova*, the concentration exceeding 2.5 mg N l^{-1} in more than 50 per cent of the rivers (*Figure 26*). In *Belgian Flanders, Bulgaria, Denmark, Moldova, Romania*, and *the United Kingdom*, more than 10 per cent of the rivers even have a nitrogen level exceeding 7.5 mg N l^{-1}.

Whereas the median nitrate concentration is only 0.18 mg N l^{-1} in Nordic rivers, it is 3.5 mg N l^{-1} in the western European countries, rivers with nitrogen levels below 1 mg N l^{-1} being rare (*Figure 28*). The nitrate levels in the rivers of southern and eastern European countries are basically the same although nitrate levels in the southern European countries are rather homogeneous whereas there are large regional differences in eastern Europe; thus the concentration is high in central European countries like *Romania, the Czech Republic*, and *Poland*, but low in the new Baltic states and large parts of *the Russian Federation*.

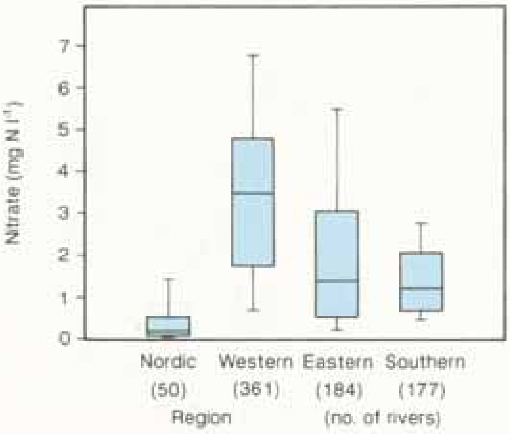


Figure 28: Annual mean nitrate concentration in rivers in four European regions. Median, upper and lower quartiles, and 10 and 90 percentiles are shown.

Human activities and nutrient concentrations in rivers

The nutrients present in rivers and lakes originate from numerous sources within the catchment area, the main ones being the natural runoff from soil and bedrock weathering, and the enhanced runoff related to various human activities such as deforestation and agriculture (fertilizer application, irrigation, etc.). In addition, many rivers are used for the removal of human waste products such as sewage water, stormwater and industrial effluent. The extent to which nutrient concentrations increase above the natural background level depends on the demographic, industrial and agricultural development in the catchment. Thus the increase is minor in sparsely populated areas with little farm land and industry, compared with that in densely populated areas with intensive agricultural and industrial production. Another important factor is the type and extent of waste water treatment, efficient high technology sewage plants being able to reduce the phosphorus content of effluents by more than 90 per cent. Finally, a ban on phosphorus in detergents can reduce phosphorus loading to rivers and lakes by more than 25 per cent, as experienced in *Switzerland* since 1985.

Phosphorus in relation to human activity

There is a positive correlation between the population density and annual mean river water phosphorus concentration. The phosphorus concentration is generally lower than 20 µg P l^{-1} in river catchments with less than 15 inhabitants km^{-2}, and higher than 200 µg P l^{-1} in those with more than 100 inhabitants km^{-2} (*Figure 29*).

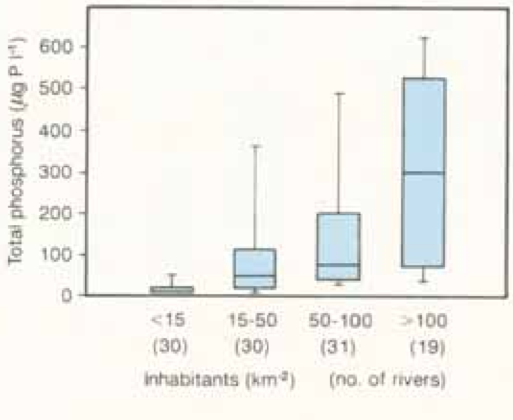


***Figure 29*:**
Relationship between annual mean total phosphorus concentration and population density in the river catchments.

In densely populated areas such as *Denmark, Western Germany, Latvia*, and the *River Po* catchment (which is inhabited by one third of *Italy's* population), 43-64 per cent of the phosphorus discharge to inland surface waters is derived from municipal sewage discharge; industrial effluent is generally less important, only accounting for 3-12 per cent of the total discharge, while agricultural activity accounts for 22-41 per cent (*Figure 30*). If there was no human activity, the phosphorus levels would only be 5-10 per cent of the current levels.

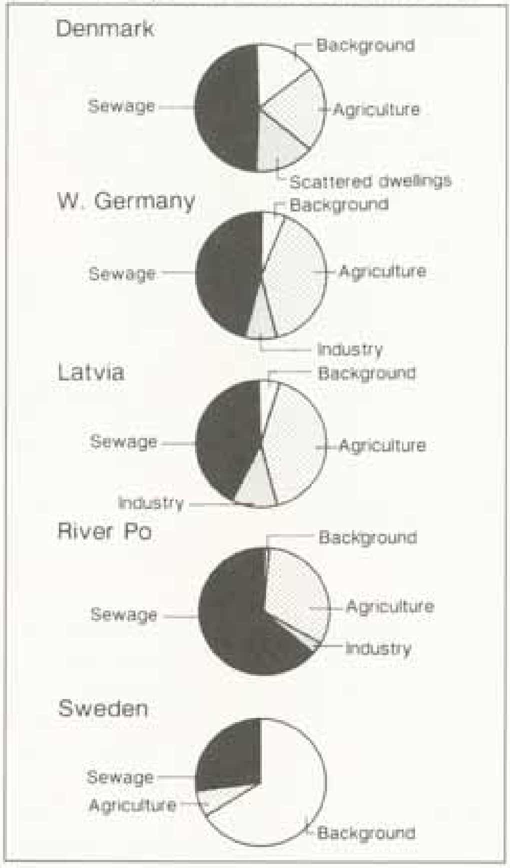


***Figure 30*:**
Source apportionment of total phosphorus discharge into inland surface waters.
(Revised from Kronvang et al. 1993; Umweltbundesamt, 1992; Carl Bro Group, 1992; Italian Ministry of the Environment, 1989; Löfgren & Olsson, 1990).

Sweden is sparsely populated, most major towns being located along the coast. The level of sewage water treatment is one of the highest in Europe. River phosphorus concentrations are consequently low (*Figures 23 & 24*), only about 27 per cent of the phosphorus discharge to inland surface waters being related to sewage and industrial effluents and about 10 per cent to agricultural activity (*Figure 30*). The remaining discharge is derived from diffuse runoff from the countryside.

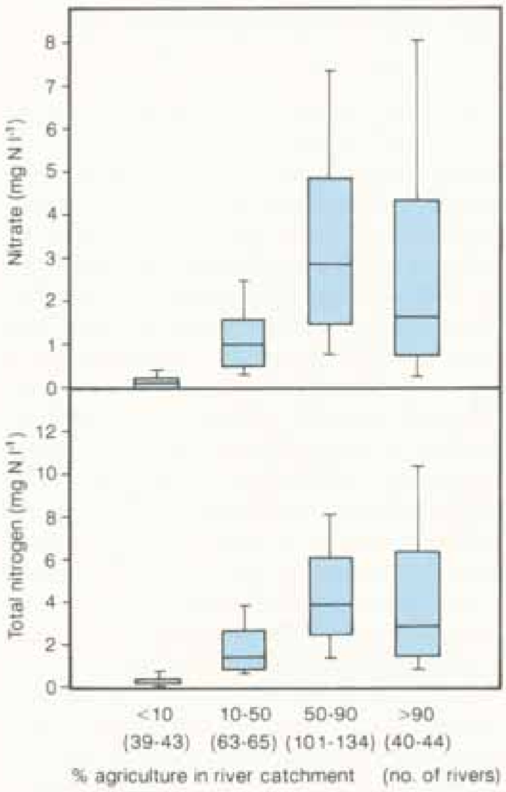


Figure 31:
Relationship between annual mean nitrate and total nitrogen concentration and percentage of agricultural land in the river catchments.

Nitrogen in relation to human activity

The elevated nitrate concentrations seen in European surface waters have in many studies been related to modern agricultural practices, particularly the use of nitrogen fertilizers (Stibe & Fleischer, 1991; Wright et al. 1991; Edwards et al. 1990; Pierre & Prat, 1989; Neill, 1989), the nitrogen concentration being significantly correlated to the percentage of farmland in the river catchments (*Figure 31*). River nitrogen levels in catchments with less than 10 per cent agricultural land are generally below 0.3 mg N l^{-1}, whereas those in catchments with 10-50 per cent agricultural land lie between 0.5 and 2.5 mg N l^{-1}. In rivers in catchment areas with more than 50 per cent cultivated land the nitrate and total nitrogen levels are generally above 1.5 and 2 mg N l^{-1}, respectively.

In *Denmark*, where farm land accounts for 65 per cent of the total area, approximately 80 per cent of nitrogen discharge to inland waters is attributable to agricultural activity (*Figure 32*). A similar high proportion is also found in *Latvia*, where 70 per cent of the nitrogen discharge is derived from agricultural activity. In *Western Germany* and in the *River Po* catchment, where agriculture is the most important nitrogen source, accounting for about 50 per cent of total nitrogen discharge, point source nitrogen discharges also play an important role, accounting for about 45 per cent of the total discharge; of this, three quarters is attributable to municipal sewage water and the remaining quarter to industrial effluent. If there was no human activity, the nitrogen levels in the above-mentioned areas would only be 10 per cent of the current levels.

In *Sweden*, where only 6 per cent of the land is cultivated and river nitrogen concentrations are usually low (*Figures 26 & 27*), approximately 40 per cent of nitrogen discharge to inland surface waters is attributable to human activities, the remaining 60 per cent being diffuse discharge from forested and uncultivated areas (*Figure 32*). Of that attributable to human activity, agricultural activity accounts for more than two thirds and point sources for the remaining third. However, in southern *Sweden* where the proportion of farm land is relatively higher, the nitrogen concentration is also higher and a greater percentage of nitrogen discharge is derived from agricultural activity (Fleischer et al. 1987).

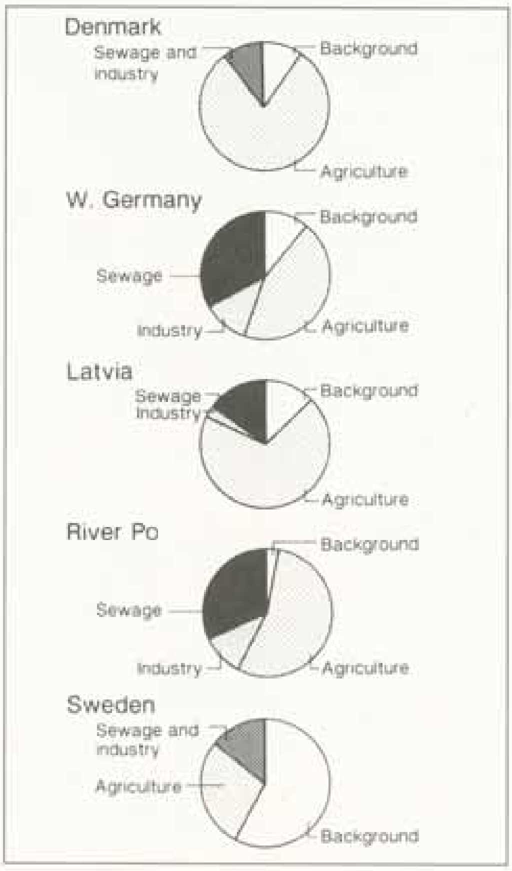


Figure 32:
Source apportionment of nitrogen discharge to rivers and lakes.
(Revised from Kronvang et al. 1993; Umweltbundesamt, 1992; Carl Bro Group, 1992; Italian Ministry of the Environment, 1989; Löfgren & Olsson, 1990).

Table 11:
Phosphorus and nitrogen concentration in lakes in relatively unpolluted areas such as mountain regions, natural parks, etc. Mean values or percentage with concentration below specified limit.

Site	Country	Number of lakes	Total phosphorus (µg P l⁻¹)	Nitrate (µg N l⁻¹)	Ammonium (µg N l⁻¹)
Sierra Nevada[1]	ES	10	3.9*	6	-
Pyrenees[2]	ES	102	~15	~139	~25
Tatra Mountains[3]	SK	10	5.7	400	14
Northern Apennines[4]	IT	43	14	112	28
Southern Alps[5]	IT	50	19	327	42
Italian Alps[6]	IT	320	<10 (86%)	14	18
Italian Alps, Aosta Valley[7]	IT	100	-	140	-
Sweden, Reference-lakes[8]	SE	154	<15 (80%)	<750#(87%)	-
North Sweden, forest lakes[9]	SE	59	13.2	350	-
Finland, forest lakes[10]	FI	135	10	-	-
Black Forest Lakes[11]	DE	6	-	429	-

* Dissolved orthophosphate # Total nitrogen

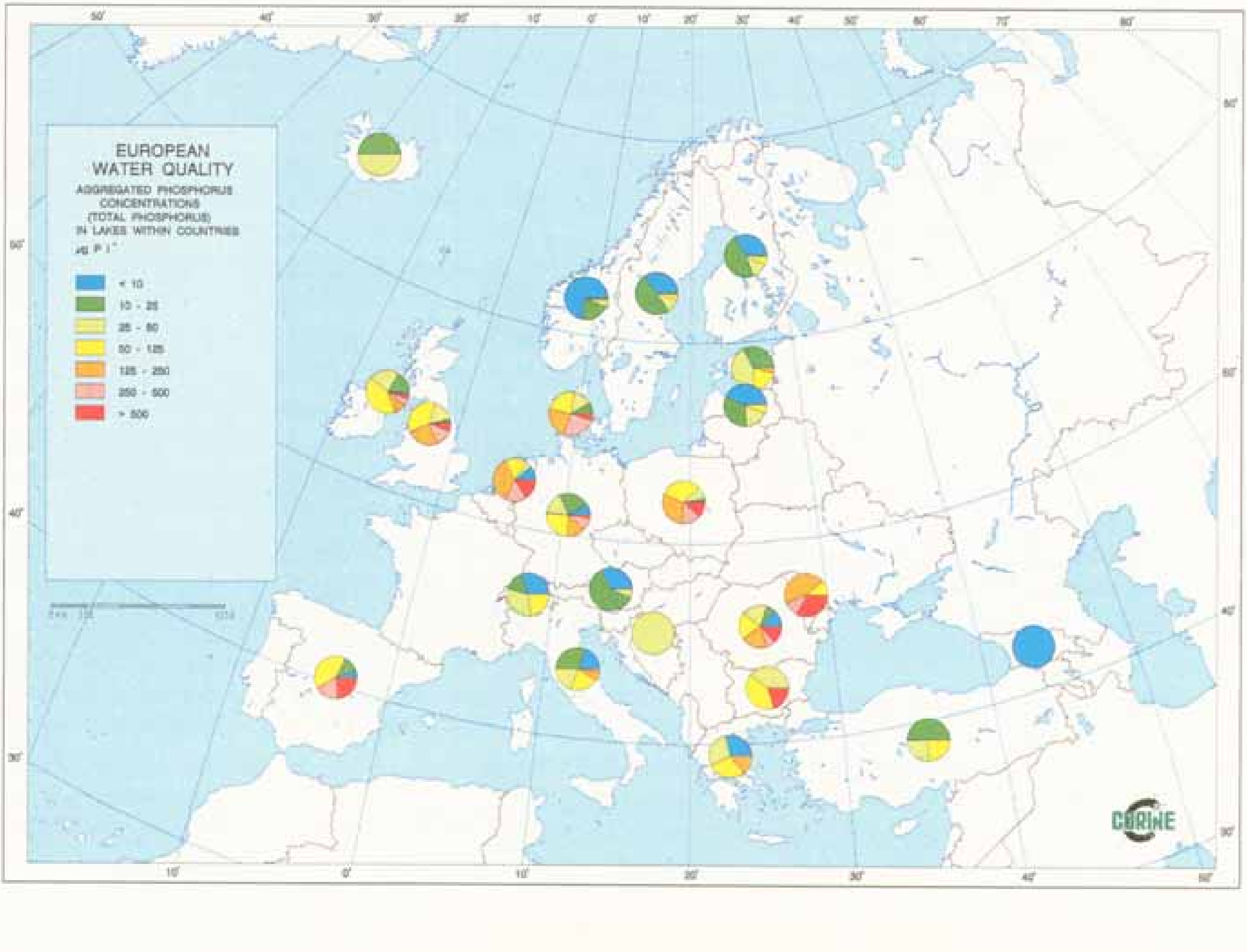
[1] Morales-Baquero et al. 1992; [2] Catalan et al. 1992; [3] Fott et al. 1992; [4] Viaroli et al. 1992; [5] Mosello, 1981; [6] Mosello, 1984; [7] Mosello et al. 1991; [8] SCB Sweden, 1990; [9] Borg, 1987; [10] Heitto, 1990; [11] Schwoerbel, 1989.

Nutrient concentrations in lakes

The nutrient concentration of the inflowing water generally determines the lake water nutrient concentration (Vollenweider, 1976; OECD, 1982). However, nutrients may be partly lost from the lake water, either to the sediment, especially in the case of phosphorus, or to the atmosphere through denitrification (in the case of nitrogen). The proportion of nutrients lost is directly related to water residence time. Nutrient levels in lakes are therefore generally lower than in their tributaries. If the external phosphorus loading of a lake is high for a period, a large amount of phosphorus will accumulate in the lake sediment; when external loading is subsequently reduced, some of the accumulated phosphorus may be released to the water and thereby delay lake recovery (Sas, 1989; Cullen & Forsberg, 1988; Marsden, 1989).

In relatively unpolluted areas such as remote mountain regions and national parks, lake nutrient levels are usually low, the total phosphorus concentration being below 10-20

Figure 33:
Frequency distribution of summer mean total phosphorus concentrations in lakes in different European countries. (Data compiled by NERI and EEA-TF for this report.)



µg P l^{-1} and the nitrogen level below 0.5 mg N l^{-1} (*Table 11*). Higher concentrations generally imply an anthropogenic influence on the lake catchment.

The frequency distribution of lake phosphorus and nitrogen concentrations gives an indication of lake water quality in each country. However, although the presence of a high percentage of lakes with low nutrient levels suggests that the water quality is generally good, the frequency distribution may be dominated by clearwater lakes in sparsely populated areas and as a consequence may not be fully representative of the relatively more important lakes in the most inhabited areas.

Phosphorus in lakes

The European lakes with the lowest phosphorus concentration are found in *Norway*, the concentration of total phosphorus being less than 10 µg P l^{-1} in more than 70 per cent of the lakes (*Figure 33*) and only exceeding 25 µg P l^{-1} in approximately 10 per cent of the lakes. In nearby *Sweden* and *Finland*, as well as in *Latvia* and *Austria*, lake phosphorus levels are also relatively low, being below 25 µg P l^{-1} in 75-90 per cent of the lakes. In *Switzerland*, *Italy*, and *Germany*, the lake phosphorus levels are higher, approximately 50 per cent of the lakes having a concentration below 25 µg P l^{-1}, and the other 50 per cent having a concentration between 25-125 µg P l^{-1}. German lakes with low phosphorus concentrations tend to be located in the Alpen Foreland, while those with high concentrations are located in the northern part of the country. In *Italy*, there are also many lakes with low phosphorus levels in the alpine regions. In *Estonia* and *Northern Ireland*, phosphorus levels in the majority of the lakes are below 50 and 125 µg P l^{-1}, respectively. In *Spain*, *England* and *Wales*, *Romania*, *Bulgaria*, *Denmark*, *Poland*, *The Netherlands*, and *Moldova*, lakes phosphorus levels are generally high, exceeding 50 and 125 µg P l^{-1} in more than 80 per cent and 45 per cent of the lakes, respectively.

Nitrogen in lakes

The frequency distribution of total nitrogen in lakes shows the same tendency as for phosphorus (*Figure 34*). The percentage of lakes with low nitrogen levels is highest in *Norway*,

Figure 34: Frequency distribution of summer mean nitrogen concentrations in lakes in different European countries. (Data compiled by NERI and EEA-TF for this report.)

where 50 per cent and 90 per cent of the lakes have nitrogen levels below 0.3 and 0.75 mg N l^{-1}, respectively. In *Sweden, Finland, Latvia,* and *Estonia*, nitrogen levels are lower than 0.75 mg N l^{-1} in the majority of the lakes. The picture is the opposite in *Denmark, Poland, Bulgaria,* and *Moldova*, where 85-90 per cent of the lakes have nitrogen levels higher than 0.75 mg N l^{-1}.

Nutrient concentrations in large lakes

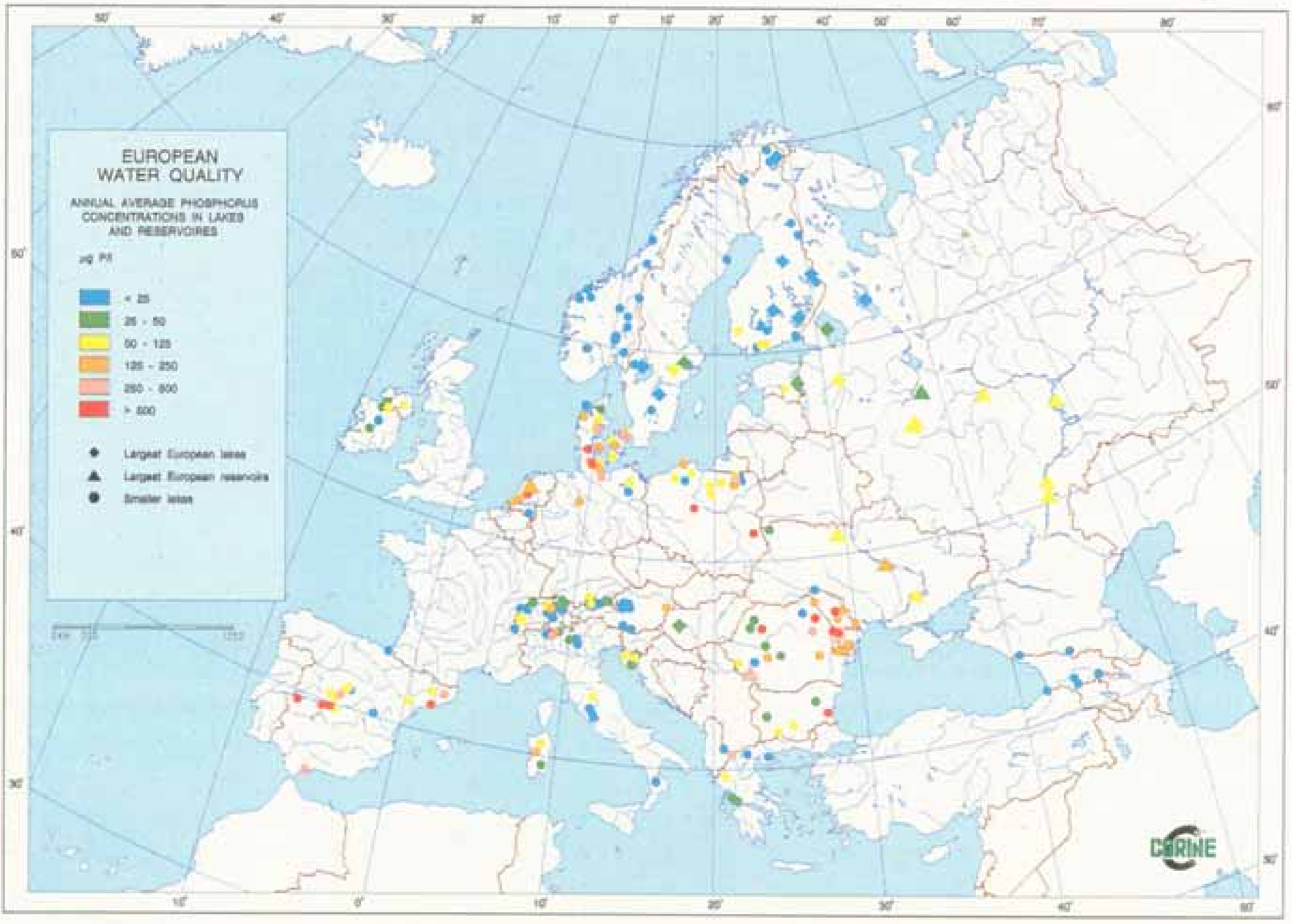
Extreme nutrient levels are rarely seen in the large European lakes, total phosphorus and total nitrogen generally being below 125 μg P l^{-1} and 1.0 mg N l^{-1}, respectively.

In the two largest European lakes, *Lake Ladoga* and *Lake Onega* in *the Russian Federation*, total phosphorus concentration is currently 26 and 10 μg P l^{-1}, respectively (*Figure 35*), levels 3-5 times higher than in the 1950s (Gutelmacher & Petrova, 1982; Petrova 1982). Although information about nutrient levels in many of the other large European lakes and reservoirs that lie in *the Russian Federation* is limited, the phosphorus concentration in *Lake Peipus* and *Lake Ilmen* is 40 and 70 μg P l^{-1}, respectively. In 13 large reservoirs on the *Volga* and *the Dnepr*, the total phosphorus concentration ranges from 49 to 201 μg P l^{-1}, the mean value being 87 μg P l^{-1} (Datsenko, 1990).

In *Sweden, Finland,* and *Norway* the large lakes usually have a phosphorus concentration below 15 μg P l^{-1}. Nevertheless, a few lakes located in more densely populated areas have higher phosphorus levels, examples being the Swedish lakes *Mälaren* and *Hjälmaren*, the concentrations of which are around 30 and 50 μg P l^{-1}, respectively. The largest lake in the British Isles, *Lough Neagh* in *Northern Ireland*, has a phosphorus level of approx. 100 μg P l^{-1}, while other large lakes in *Ireland* and the large lochs in *Scotland* generally have low phosphorus concentrations. The majority of large lakes in *The Netherlands, northern Germany, Denmark,* and *Poland* have phosphorus levels around or exceeding 100 μg P l^{-1}.

Large lakes in the Alps have phosphorus concentrations ranging from 10 to 60 μg P l^{-1}, the concentration in the largest lakes being approximately as follows: 60 μg P l^{-1} in *Lac Léman*, 50 μg P l^{-1} in *Bodensee*, 10 μg P l^{-1} in *Lago di Garda*, 30 μg P l^{-1} in *Lake Neuchâtel*, and 18 μg P l^{-1} in *Lago Maggiore*. The two large lakes

Figure 35:
Total phosphorus concentration in large European lakes and reservoirs.
(Data compiled by NERI and EEA-TF for this report.)



at the Hungarian Plain, *Lake Balaton* and *Neusiedler See*, have phosphorus levels of 40-100 µg P l^{-1}, respectively, while the lakes in the mountains between *Albania*, *Greece*, and *The Former Yugoslav Republic of Macedonia* generally have low phosphorus levels.

Impact of nutrients on lake water quality

Phosphorus is usually the nutrient that most frequently limits plant growth in lakes and reservoirs. Many studies have shown that the amount of phytoplankton (generally measured as the level of the photosynthetic pigment, chlorophyll) increases in lakes with increasing phosphorus levels (eg. OECD, 1982; Canfield & Bachman, 1981; Berge, 1987; Jeppesen et al. 1991). The increase in phytoplankton concentration reduces water transparency and at high nutrient levels the lake water becomes very turbid.

In lakes with mean summer total phosphorus concentrations lower than 10 µg P l^{-1}, chlorophyll concentrations are low and the water is clear, ie. water transparency is high (*Figure 36*). With increasing phosphorus concentrations chlorophyll concentrations rise and water transparency declines. Thus in lakes with phosphorus concentrations between 50 and 125 µg P l^{-1}, the chlorophyll concentration ranges from 10 and 50 µg l^{-1}, and water transparency is reduced to 1-2 m. At phosphorus concentrations exceeding 125 µg P l^{-1} the chlorophyll concentration may reach very high concentrations, and water transparency becomes reduced to less than 1 m. However, in lakes with extremely high phosphorus concentrations, ie. above 500 µg P l^{-1}, the increase in chlorophyll levels out and the biological structure becomes very unstable, and fish kill may occur (Søndergaard et al. 1990).

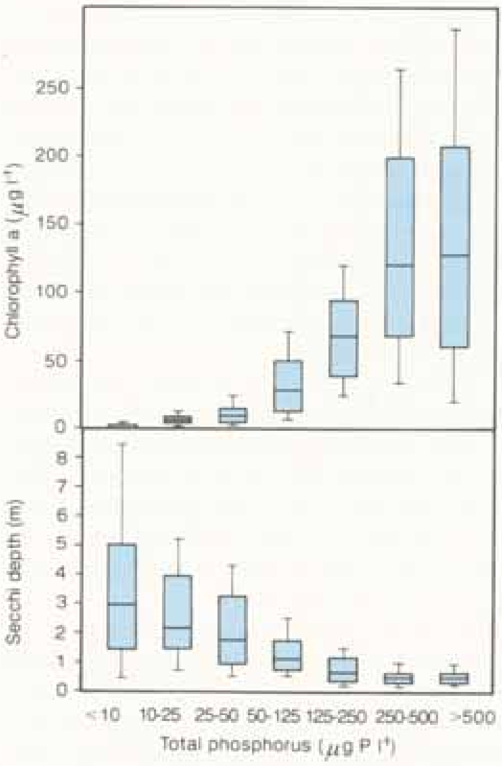


Figure 36: Relationship between summer mean lake water concentration of total phosphorus and chlorophyll and water transparency.

Median, upper and lower quartiles, and 10 and 90 percentiles are shown for lakes in the phosphorus classes.

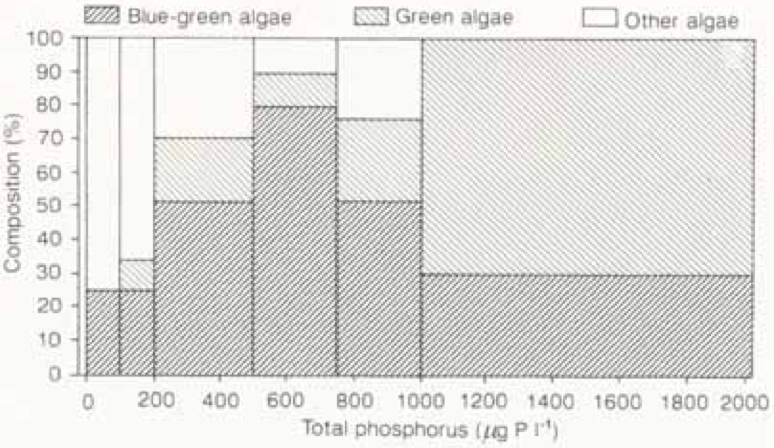


Figure 37: Relationship between total phosphorus concentration (May-September) and blue-green algae dominance in 300 shallow Danish lakes.

(Redrawn from Jeppesen et al. 1991).

Blue-green algae and phosphorus

In lakes with high phosphorus levels, excessive growth of blue-green algae may lead to surface scum and the production of toxins potentially poisonous to fish, cattle, dogs, and man. Data from 300 shallow Danish lakes indicates that blue-green algae are of minor importance in the summer at phosphorus levels below 50 µg P l^{-1}, but become increasingly important at higher phosphorus levels (*Figure 37*). They become the dominant phytoplankton group at phosphorus concentrations from 200-1000 µg P l^{-1}. In deeper lakes, however, blue-green algae tend to dominate at even lower phosphorus levels, and the concentration generally has to be below 20 µg P l^{-1} in order for blue-green algae not to become dominant in the summer (Sas, 1989).

Trends in nutrient concentrations

Time series data for the period 1977-90 concerning nutrient concentrations in more than 250 European rivers has been collated for this report. Most of the time series cover the whole period but, especially in the case of southern European rivers, some of the time series only cover the last 5-8 years.

Phosphorus trends

The increase in phosphorus levels that occurred in many lakes during the 1960s and 1970s caused severe eutrophication problems and led several countries to take measures to reduce phosphorus discharge to rivers and lakes. This was primarily achieved by reducing discharge from point sources, especially waste water, by improving waste water treatment. In some countries part of the reduction was achieved by reducing or banning phosphorus in detergents.

The reduction in phosphorus loading is reflected by a marked decrease in the phosphorus levels of many European rivers (*Figure 38*), the phosphorus concentration in the majority of rivers (64 per cent) having decreased between the periods 1977-82 and 1988-90. In one third of the rivers, the reduction was greater than 25 per cent.

While the phosphorus concentration decreased in the majority of rivers in the nordic cuontries and in western and southern Europe, it rose in many eastern European rivers, this being largely explicable by increased loading and very limited construction (in eastern European countries) of sewage plants incorporating phosphorus removal. The reduction in phosphorus levels was most marked in western Europe, a reduction of more than 25 per cent being observed in half of the rivers. Nevertheless, high phosphorus levels are still to be found in the rivers of western Europe.

A reduction in phosphorus loading and concentration has also been observed in several European lakes during the last 20 years (*Table 12*). During the 1950s and 1960s an increase in phosphorus concentration caused environmental deterioration in many of the large lakes in the Alps (*Figure 39*). Action plans were consequently implemented in the 1970s with the objective of reducing phosphorus loading. As a result there was a marked reduction in phosphorus levels during the 1980s. In the two largest alpine lakes, *Lac Léman* and *Bodensee*, the phosphorus level has been reduced from about 90 $\mu g\ P\ l^{-1}$ in both lakes to 60 and 50 $\mu g\ P\ l^{-1}$, respectively (Stabel, 1991; Lang, 1991). However, these concentrations are still high, and little improvement has been observed in the ecological water quality (Tilzer et al. 1991; Lang, 1991).

In *Denmark* there has been a general reduction in the phosphorus level of many lakes

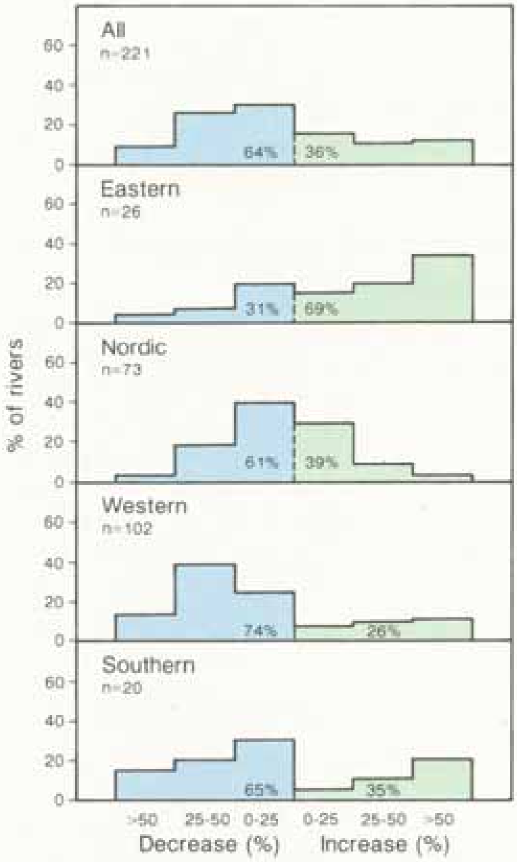


Figure 38:
Percentage of rivers in which annual mean river total phosphorus concentration decreased or increased between the periods 1977-82 and 1988-90.

Table 12:
European lakes with reduced phosphorus concentration during the last 15 to 30 years.

Country	Lake(s)	Period	Percent reduction in in-lake phosphorus level
Europe[1,2]	9 shallow lakes	Mid 1970's to late 80's	63
Europe[1,2]	9 deep lakes	Mid 1970's to late 80's	51
CH[3]	Walensee	1979 to 88	92
AT[4]	Mondsee	1979 to 89	70
SE[5]	Vättern	1962 to 86	57
IT[6]	Lago Maggiore	1977 to 88	46
CH,AT,DE[3,7]	Bodensee	1979 to 89	45
CH,FR[8]	Lac Léman	1976 to 89	36
DK[9]	46 lakes	1972-79 to 1985-89	33
CH,IT[10]	Lago di Lugano	1984 to 90	32
CH[3]	Zürich See	1979 to 88	31

[1]Sas, 1989; [2]Seip et al. 1990; [3]Stabel, 1991; [4]Dokukil & Jagsch, 1992; [5]Persson et al. 1989; [6]Mosello, 1989; [7]Tilzer et al. 1991; [8]Lang, 1991; [9]Kronvang et al. 1993; [10]Barbieri & Mosello, 1992.

(*Figure 40A*), but without any significant improvement in water transparency (*Figure 40B*); this discrepancy may be explained by the fact that the phosphorus level still exceeds 125 µg P l^{-1} in 70 per cent of the lakes, water transparency therefore generally being less than 1 m (*Figure 36*).

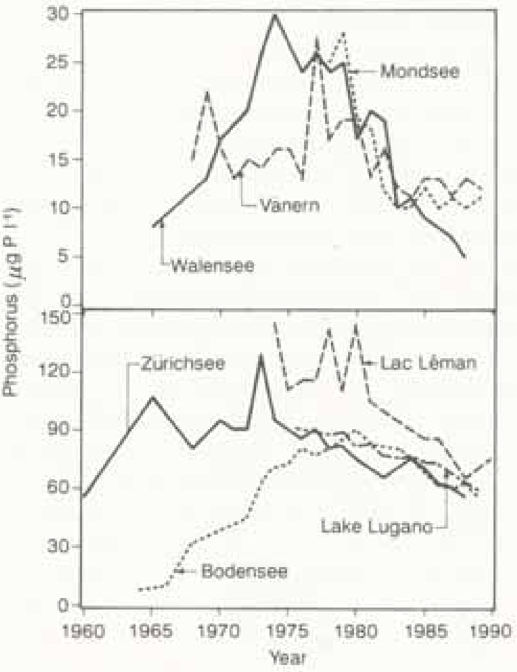


***Figure 39*:**
Trends in the phosphorus concentration of seven European lakes.
(Walensee, Zürichsee and Bodensee after Stabel, 1991; Mondsee after Dokulil & Jagsch, 1992; Vänern after Olsson, 1991; Lac Léman after Lang, 1991; Lake Lugano after Barbieri & Moselo, 1992).

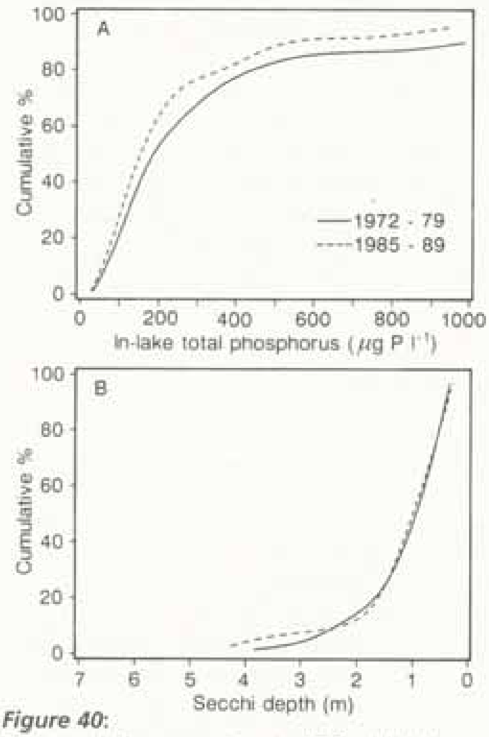


***Figure 40*:**
The cumulative percentage in 46 Danish lakes during the periods 1972-79 and 1985-89 of:
A) in-lake total phosphorus concentration, and
B) summer water transparency (Secchi depth).

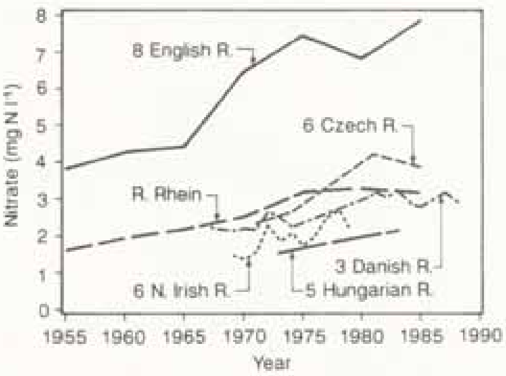


***Figure 41*:**
Trends in the nitrate concentration of European rivers.
(José, 1989; Van der Weijden & Middelburg, 1989; Czechoslovakia, 1992; Smith et al. 1982; Hock & Somlyódy, 1989; Kristensen et al. 1990).

Nitrogen trends

Nitrate levels have tended to increase in many European rivers over the last 20-40 years (*Figure 41*), the same applying to European lakes (Barbieri & Mosello, 1992; Tilzer et al. 1991; Mosello, 1989; Henriksen et al. 1988). The increase in river and lake nitrate levels is mainly attributable to a corresponding increase in the use of nitrogen fertilizers in most European countries (*Figure 42*). However, the increase in lake nitrate levels in areas with relatively low human activity, eg. *Norway*, is mainly attributable to increased atmospheric deposition of nitrogen caused by the burning of fossil fuels and agricultural activity (Henriksen et al. 1988). A decrease in the ammonium level in European rivers is expected as consequence of general improvement in waste water treatment and a growing awareness of the problem of agricultural pollution with manure and silage.

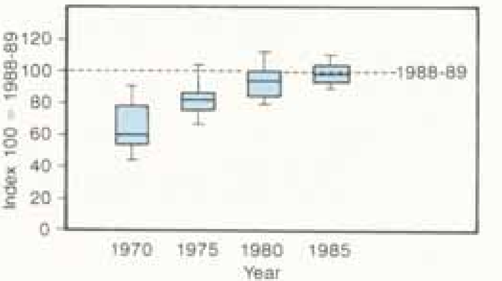


***Figure 42*:**
Trends in nitrogen fertilizer usage in European countries (Eurostat).

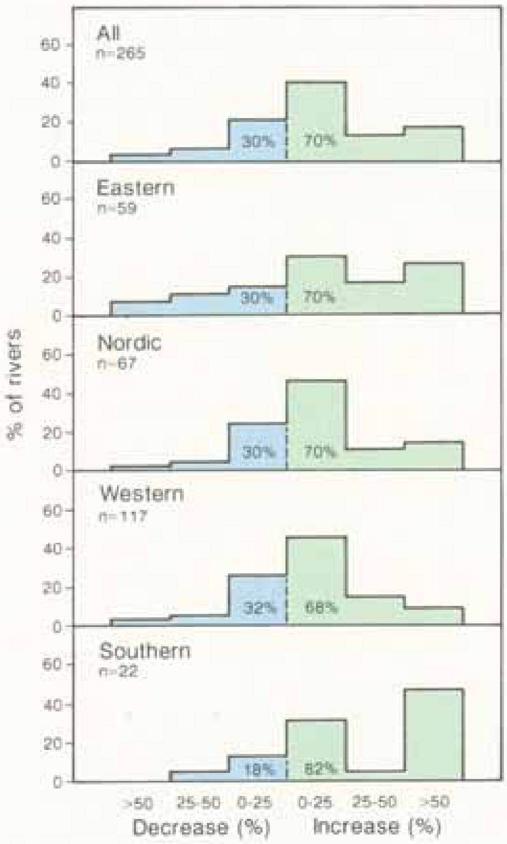


Figure 43:
Percentage of rivers in which annual mean river nitrate concentration decreased or increased by the ranges shown between the periods 1977-82 and 1988-90.

Nitrate trends

Nitrate levels increased between the period 1977-82 and 1988-90 in more than two thirds of European rivers, the median concentration increase being 0.14 mg N l^{-1} ie. 13 per cent (*Figure 43*). The percentage of rivers in which the concentration increased was nearly identical in the four regions of Europe, but the median concentration increase varied, being 0.013 mg N l^{-1} in Nordic rivers and 0.18, 0.49, and 0.35 mg N l^{-1} in the rivers in the western, eastern, and southern European countries, respectively. The increase in nitrate concentration was most marked in eastern and southern European rivers, this being explicable by the marked increase in the use of nitrogen fertilizers during the same period. In many western European countries, in contrast, the increase in the use of nitrogen fertilizers peaked in the late 1970s and remained at that high level during the 1980s.

Ammonium trends

The ammonium level in 70 per cent of 230 European rivers decreased markedly between 1977-82 and 1988-90 (*Figure 44*). The decline was most significant in rivers in which the ammonium level was between 0.5-1 mg N l^{-1} in the period 1977-82, the ammonium level falling to below 0.5 mg N l^{-1} in the majority of these rivers. The decreasing trend in ammonium levels is in concert with the decline in organic matter content of the water (*Figure 21*), and can be explained by improved waste water treatment and the consequent reduction in organic matter discharge. The reduction in ammonium levels was most significant in the western European and Nordic countries, while the concentration tended to increase in many eastern European rivers.

Summary

In general, nutrient levels are lowest in the rivers of the sparsely populated Nordic countries, and highest in those in a band stretching from the southern part of *the United Kingdom* to the Balkan area and *the Ukraine*. There is a close relationship between phosphorus concentrations and catchment population density, and between nitrogen levels and the percentage of the catchment that is agricultural land. Most of the phosphorus loading of inland surface waters is attributable to discharge from point sources, especially municipal sewage water and industrial effluent, while the nitrogen loading is primarily de-

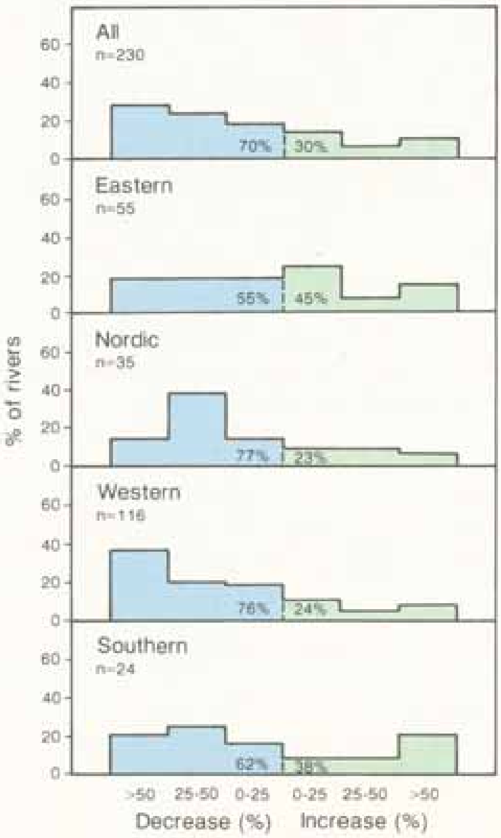


Figure 44:
Percentage of rivers in which annual mean river ammonium concentration decreased or increased by the ranges shown between the periods 1977-82 and 1988-90.

rived from agriculture activity, especially from the use of nitrogen fertilizers and manure.

Many European lakes also have high nutrient concentrations, those with the highest nutrient levels being located in densely populated areas. Because of the high nutrient levels, many of the lakes have high concentrations of phytoplankton and as a consequence very turbid water.

The phosphorus concentration in the majority of European rivers and many lakes has decreased during the last 10-15 years as a consequence of improved waste water treatment. The ammonium level in many European rivers has also declined, this being mainly attributable to improved waste water treatment and increased awareness of the importance of correct handling and storage of manure and silage. The improvement has been most marked in the western European rivers, the levels having increased in many eastern European rivers. In contrast to the phosphorus and ammonium levels, the nitrate level in most European rivers has increased during the last 10-15 years, mainly as a result of the increasing use of nitrogen fertilizers.

Conclusion

The nutrient levels in many areas of Europe are still too high, and unless drastic efforts are made to reduce inputs of nutrients, eutrophication is likely to continue to be an important European environmental issue. Phosphate removal in waste water treatment plants and reducing the phosphorus content of detergents, supplemented with measures to reduce in particular nitrogen but also phosphorus loading from agricultural areas are in many cases a necessity.

Acidification of surface waters

Surface water acidification has been of public concern since the early 1970s, awareness of the problem having been aroused by episodes of severe fish kill in rivers and lakes in the southernmost part of *Norway*, and along the west-coast of *Sweden* (Overrein et al. 1980; Monitor 12, 1991). These episodes of fish kill were attributed to "acid rain", ie. precipitation acidified by the burning of fossil fuels in industry and human settlements. Norwegian and Swedish observations have indicated that the emission of acidifying gaseous by-products such as sulphur dioxide and nitrogen oxides was the main cause of acidic precipitation in areas situated up to hundreds of kilometres from the source.

Studies were initiated to evaluate the extent, the cause/effect relationships, and the chemical and biological impact of surface water acidification in *Norway* and *Sweden* (Overrein et al. 1980; National Swedish Environment Protection Board, 1983). It was found that of a total of 5000 lakes in a 28 000 km^2 region of southern *Norway*, 35 per cent had lost their fish populations. In southern and central *Sweden*, damage to fish communities was observed in 2500 lakes; however, on the basis of lake pH, and from the knowledge that many fish species are unable to tolerate pH-levels below 5.5, it was estimated that the fish populations of about 18 000 lakes were affected.

Surface water acidification and damage to freshwater life have since been documented in numerous studies (eg. Muniz, 1991). Over the last two decades, surface water acidification caused by the atmospheric emission of sulphur dioxide and nitrogen oxides has been recognized as a serious environmental problem in most European countries, as well as in North America (Merilehto et al. 1988; Howells, 1990; Skjelkvåle & Wright, 1990). In the mid1980s a further acidifying air pollutant was identified. Laboratory studies in *The Netherlands* documented that the deposition of ammonia volatilized from agricultural areas where cattle and pig concentrations could be a major cause of acidification in soft water lakes (Schuurkes et al. 1986; van Dam, 1987; van Breemen & van Dijk, 1988).

The acidifying effect of atmospheric deposition has been documented from studies in nature reserves and remote mountain lakes (Mosello et al. 1992b) where the only possible influence of human activity is through atmospheric deposition. In areas with industrial and agricultural activity, several factors that can positively or negatively affect surface water acidity have to be taken into account, for example mining, afforestation, clear-cutting, draining, crop removal, fertilization, liming, etc. Internal processes in lakes (eg. reduction and oxidation processes) may also influence their acid/base status. These various factors are described in standard textbooks, for example Cresser & Edwards (1987); Howells (1990); Monitor 12 (1991).

Geographical distribution of acidification

Surface water acidification can be expected in areas where acidic deposition is high and the catchment soil or bedrock is poor in lime and other easily weatherable minerals that buffer against acid precipitation. Small high altitude lakes and streams are generally more severely affected than larger lowland surface waters, the latter usually being acidified only in well leached, sandy areas covered by heath or forest. Dune lakes and pools may also be acidified. Even naturally acidic bog lakes (eg.

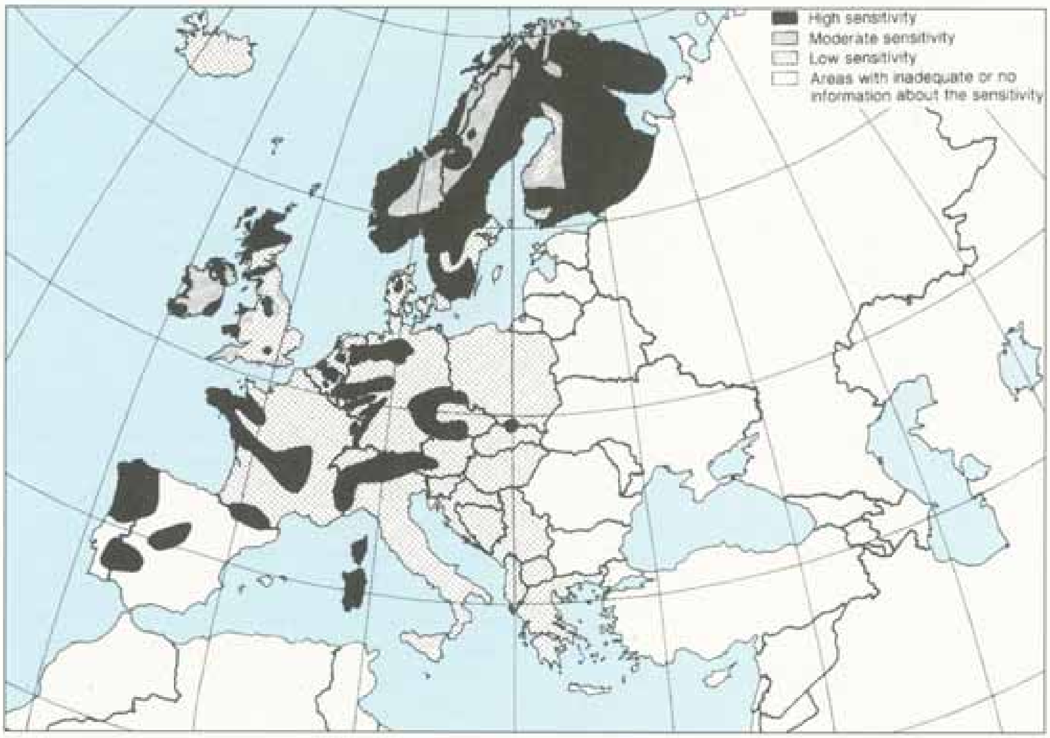


***Figure 45*:** Areas of Europe geologically sensitive to surface water acidification. (Redrawn from Skjelkvåle & Wright, 1990; Merilehto et al. 1988).

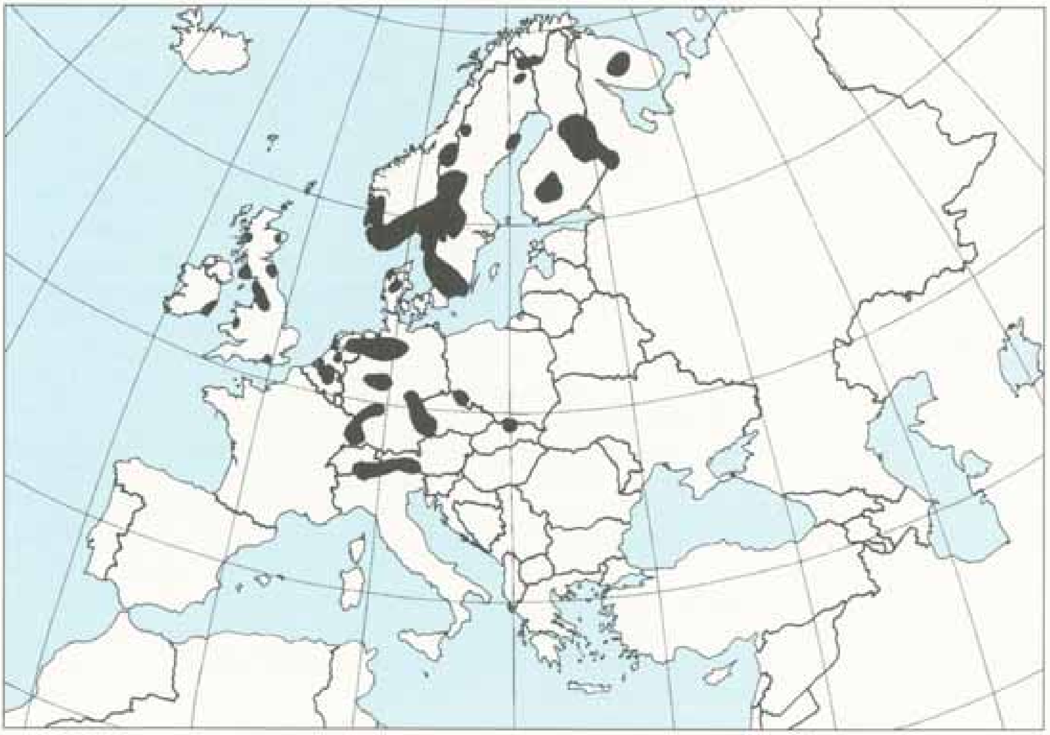


***Figure 46*:** Areas of Europe where surface water acidification has been observed. (Redrawn from Skjelkvåle & Wright, 1990; Merilehto et al. 1988).

in the Campine region of *Belgium*) may be further acidified by acid precipitation, thereby changing their ecology.

Geological characteristics render large areas of Europe sensitive to surface water acidification if exposed to acidic atmospheric deposition (*Figure 45*). The areas of Europe where surface water acidification has actually been observed are shown in *Figure 46* and the current state of surface water acidification in Europe is briefly summarized below. A more comprehensive summary can be found in Merilehto et al. (1988); Howells (1990); and Skjelkvåle & Wright (1990).

In southern *Finland*, *Sweden*, and *Norway*, lake and river acidification increased slowly from 1915-50 and rapidly from 1950-80. Since then conditions have remained relatively unchanged, possibly as a result of a reduction in acidic deposition (Brodin & Kuylenstierna, 1992). In southern *Norway*, lake sulphate concentration tended to decrease between 1974 and 1986 in line with the decrease in sulphur emission in western Europe. Surprisingly, however, this was not accompanied by a decrease in lake acidity (Norwegian State Pollution Control Authority, 1987). The reason could be the two-fold increase in nitrate concentration that occurred during the same period as a result of an increase in the emission of nitrogen oxides. According to a Swedish survey undertaken in the winter of 1990, 45 per cent of the 85 000 lakes in Sweden had a winter pH below 6.0, and 7 per cent had a pH below 5.0 (Monitor 12, 1991). Most of the acidic lakes were small however, 23 per cent of lakes smaller than 0.1 km^2 had a pH below 5.5, but only 2 per cent of lakes larger than 1 km^2 (Monitor 12, 1991). In *Finland* about 10 per cent of 1000 lakes were found to be seriously affected (Merilehto et al. 1988; Wahlström et al. 1993). Lake acidification has also been found in the *Russian Federation* in Karelia and in the Kola Peninsula. As surface waters in Karelia have a high humus content, mean pH is 6-7 (Merilehto et al. 1988).

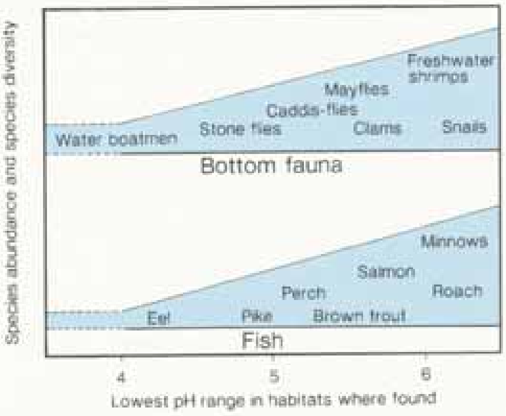
Most surface waters in western and central Europe are not as seriously affected by acidification as those in *Finland*, *Sweden* and *Norway*, despite the fact that acidic deposition is greater; this is explicable by the soil of western and central Europe being generally well-buffered, and therefore able to neutralize the acid deposition. In *the United Kingdom* acidified surface waters are found in various regions, but primarily in areas dominated by acidic soils in *Scotland*, *northern England*, and *Wales* (Howells, 1990). In parts of *Scotland* (Battarbee, 1989) and *Wales* (Jenkins et al. 1990) afforestation in areas heavily loaded by sulphur oxides has exacerbated river acidification, while in more pristine areas such as the northernmost part of *Scotland*, acidification has not occurred despite an increase in seasonal input through canopy interception. In *Ireland* there is little evidence of surface water acidification attributable to acidic precipitation. However, rivers draining catchments of soil poor in buffering capacity were more acidic when the catchment was covered with evergreen forest than without evergreen forest, the increased acidity being attributable to the scavenging of acidifying air pollutants by the canopies of the evergreen trees, and therefore affected by acid rain (Bowman, 1991). In *The Netherlands* 50-60 per cent of about 5000 small lakes are acidic (Leuven et al. 1986). Furthermore, of 187 randomly selected soft waters, mainly small isolated moorland and dune pools and lakes, 35 per cent were extremely acid with pH below 4.0. Although the main cause of this acidification is believed to be deposition of acidifying air pollutants, oxidation of sulphides in the soil is a contributing factor under certain geological conditions.

Surface water acidification has also been recorded in *Belgium*, *Denmark*, *Germany*, *Poland*, *the Czech Republic*, *the Slovak Republic*, *Austria*, *France*, *Switzerland*, and *Italy* (Merilehto et al. 1988). Acidification of high altitude lakes has been recorded from a workshop in 1991 on remote mountain lakes (Mosello et al. 1992b). Studies of such lakes are important because many of them are acid-sensitive and atmospheric deposition is the main source of pollution (Wathne, 1992). Acidification has been recorded in mountain lakes in *Italy* (Mosello et al. 1992a; Schmidt & Psenner, 1992), *the Slovak Republic* (Fott et al. 1992) and *the Czech Republic* (VeselΩ & Majer, 1992). In contrast, no acidified lakes were recorded in the Pyrenees (Catalan & Camarero, 1992) and in the northern Apennines (Viaroli et al. 1992). Acidification of lakes and rivers in forested areas has been recorded in the Vosges Mountains, the Schwarzwald, the Bavarian Forest, Thüringerwald, and Erzgebirge. Acidification of small, isolated seepage lakes has been recorded in lowland areas of *The Netherlands*, *Belgium*, *Denmark*, and northern *Germany*, mainly in regions dominated by sandy soils of low buffering capacity (Merilehto et al. 1988).

Impact of acidification

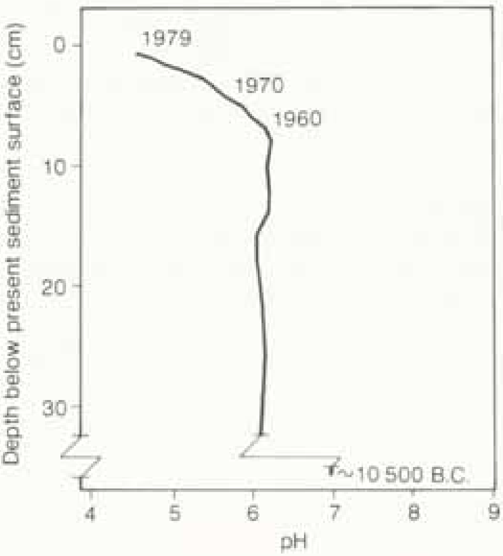
Acidification affects aquatic ecosystems at all levels and has a profound impact on both plant and animal communities. Aquatic organisms are influenced both directly, because of the resulting toxic conditions, and indirectly, because of the loss of acid sensitive species in the ecosystem and the subsequent change in ecosystem structure. One of the first recorded effects of acidification caused by man was a decrease in fish diversity in the Nordic countries (Overrein et al. 1980; Drabløs & Tollan, 1980).

Figure 47:
Acid tolerance of various benthic invertebrates and fish.



Aquatic organisms have extremely different tolerance levels towards acidification, as illustrated for various species/groups of benthic invertebrates and fish in *Figure 47*. The toxicity of acid fresh waters towards fish is only partly attributable to the low pH. In most cases, the crucial toxic factor is the content of inorganic aluminium ions that have been leached from minerals in the catchment and subsequently transported to the lakes and streams (Drabløs & Tollan, 1980; Muniz, 1983).

Figure 48:
pH in lake Gårdsjön, Sweden, calculated from the sediment subfossil diatom flora
(Redrawn from Renberg & Wallin, 1985).



That acidification can severely affect aquatic ecosystems is especially well documented from *Sweden* and *Norway*. For example, from 1940-75, 1750 of 5000 lakes in southern *Norway* became completely devoid of fish as a result of acidification, with another 900 lakes being seriously affected (Overrein et al. 1980). Fish kill on such a scale is detrimental both for commercial fishery and recreation, and represents a major loss in terms of economy and life quality.

Acidification trends

There is good evidence that many lakes have become acidified during the past 100 years, this having been documented both chemically and by palaeolimnological studies of pH-indicator species such as diatoms in lake sediment cores (Charles et al. 1990; Howells, 1990). An example is the study of lake *Gårdsjön* in *Sweden* where as a result of natural acidification processes pH fell slowly from pH 7 to 6 over the 12 500 years from the end of the last ice age until 1960. Since then it has rapidly fallen from pH 6 to 4.5 (*Figure 48*). The pH determined in this way agrees reasonably well with measured lake water pH, which was 6.3 in 1948, and 4.7 in 1977 (Wright, 1977). Increasing pH has also been recorded in fresh waters in *Finland, Sweden, Norway, the United Kingdom, The Netherlands, Belgium, Denmark,* and *Germany* (Charles et al. 1990; Monitor 12, 1991).

Critical loads

In 1979, 35 member countries of the United Nations Economic Commission for Europe (UNECE) signed the Convention on Long-Range Transboundary Air Pollution. Within the framework of this convention protocols have been drawn up concerning sulphur and nitrous oxides. The sulphur protocol states that by 1993, signatories should have reduced their sulphur emissions to levels at least 30 per cent below the 1980 levels. The protocol restricting emission of nitrous oxides was drawn up in 1988 (Brodin & Kuylenstierna, 1992). Because these abatements would not be sufficient for protecting all sensitive ecosystems, the concept of "critical load" emerged in order to establish reduction strategies for emissions of sulphur and nitrogen oxides, which, in contrast to the preceding strategy, should be based on scientific knowledge of the capacity of different ecosystems and sites to withstand various types of acid deposition.

Since the early 1980s both the "target load" (ie. a political goal for loading reduction) and the "critical load" have been extensively explored. Since 1988 the most widely used definition of the critical load for surface waters has been: "A quantitative estimate of the loading of one or more pollutants below which significant harmful effects on specified sensitive elements of the environment are not likely to occur according to present knowledge" (Kämäri et al. 1992).

The emission reduction needed to reach critical loads for nitrogen and sulphur are estimated to be as high as 70-80 per cent for southern *Sweden* and southern *Norway*, and even higher for other European countries (Brodin & Kuylenstierna, 1992).

The critical load concept appears to be a rational method for quantifying the extent to which acidic deposition and hence emission must be reduced in order to protect sensitive sites or ecosystems. Furthermore, the concept has now found acceptance in political negotiations concerning reduction strategies. European critical load maps have been prepared by the Coordination Center for Effects (Hettelingh et al. 1991).

Heavy metals, organic micropollutants, radioactivity, and other hazards

Human activity leads to chemical compounds being discharged into the aquatic environment in various ways, eg. in domestic sewage water and industrial effluent, through mining and through atmospheric deposition. While some of these compounds are known to be toxic, the environmental impact of many others remains to be elucidated. Nevertheless, these contaminants together represent a threat to both the aquatic ecosystem per se, and to human health – a threat that is intensified by the vast number of new synthetic organic compounds being produced and released into the environment.

Heavy metals

Production and use of heavy metals has increased markedly in Europe during the 19th and 20th centuries. As a result heavy metal contamination of inland surface waters has also increased, the main sources being mining and industrial activities. Other important sources are sewage discharge, runoff from the land and atmospheric deposition. In the 1970s surface water concentrations of heavy metal levels reached alarming proportions and regulations were therefore implemented to control heavy metal release at the source (Meybeck et al. 1989; RIVM, 1992). Although this has led to reduced levels of harmful metals in many western European rivers during the last decade (RIVM, 1992; Department of

Photo: Paul Conklin/NORDFOTO

Environment, 1992; Umweltbundesamt, 1992), the level is still high in some European rivers.

General assessment of the state of heavy metal pollution of European rivers and lakes is difficult, primarily because measurement of metals is rarely included in monitoring programmes, but also because concentration levels are usually so low that problems arise with sample preparation and methodological precision. Until recently metals have generally been analysed either as total water concentration or the dissolved fraction, while the latest observations suggest that anthropogenic inputs generally can be evaluated from particulate associated metals (Meybeck et al. 1989). Comparison and assessment of the state of heavy metals in European rivers is therefore even more difficult than for many of the other water quality variables.

Table 13:
Descriptive statistics for heavy metals in European river stations.

	Number of river stations	EC Drinking water standard ($\mu g\ l^{-1}$)	Percentage of river stations with values below ($\mu g\ l^{-1}$)			
			25%	50%	75%	90%
Copper	192	1000	1.6	4.8	8.0	16.0
Zinc	176	5000	5.0	10.4	36.0	91.0
Cadmium	145	5	0.0	0.0	0.4	1.8
Mercury	163	1	0.0	0.0	0.2	1.1
Lead	72	500	0.8	2.7	6.7	11.0
Chromium	56	50	1.3	4.3	11.5	17.0
Nickel	48	-	0.8	4.3	15.2	26.0

These reservations should be borne in mind when considering the following evaluation of heavy metals in European rivers. It has been possible in this report to collate data on total heavy metal concentrations in more than 200 European rivers (*Table 13*). In general, the concentrations are well below standards for drinking water, and only cadmium and mercury exceed drinking water standards in some rivers. It should be remembered, however, that the aquatic biota is usually affected by much lower concentrations: thus while the drinking water standard for copper is 1 mg Cu l^{-1}, salmonoid fish are affected at 10-50 μg Cu l^{-1} (Hodson et al. 1979). Statistical descriptive variables, ie. the median, 10 and 90 percentiles, of heavy metals in European rivers were found to be nearly identical to those for a river data set covering the whole world (Meybeck et al. 1989).

Heavy metal levels were generally lowest in the rivers of the sparsely populated Nordic countries, while those in the rivers of western, eastern, and southern European countries were roughly the same.

Some of the river stations had high concentrations of heavy metals, in particular the upstream reaches of the *Wisla*, *Oder*, and *Elbe* (where the majority of the Polish and Czech heavy industry is located), the *Danube* and many of its tributaries, and some of the rivers of *the Ukraine*. These heavy metal "hot spots", which are generally located near mining areas or near industries using large quantities of metals, are only examples: a more extensive survey would undoubtedly reveal many more locations with high levels of many metals.

The increase in acid deposition described in the previous section has led to increased mobilization of metals from the soil, and hence to elevated metal levels in the aquatic environment; thus increased levels of aluminium in surface waters and elevated levels of mercury in fish have been found in areas of Europe known to be acidified (Henriksen et al. 1989; Andersson et al. 1987).

The problems associated with heavy metal contamination of inland surface waters are illustrated below using cadmium, copper and zinc as examples. All three illustrate the impact of human activity; cadmium because it is highly toxic, both to the aquatic biota and to humans, and copper and zinc because they tend to be present in relatively high concentrations and are frequently measured.

Cadmium

Cadmium ranks among the most hazardous metal pollutants, cadmium-induced Itai-Itai disease in the Japanese *Jinzu* river basin being a frightening reminder of its toxicity (Nogawa, 1981). The cadmium concentration in natural waters unaffected by man is generally less than 1 μg Cd l^{-1} (Meybeck et al. 1989). Although cadmium levels in European rivers rarely exceed 1 μg Cd l^{-1}, there are a few rivers with high cadmium concentrations, especially the *Iskūr* in *Bulgaria*, the rivers *Guadiana* and *Tajo* in *Portugal*, and the *Danube* in *Romania*. The cadmium that is discharged into inland surface waters accumulates in the sediment; cadmium accumulation in sediment of several European rivers and lakes has been documented.

A study of the cadmium cycle in the *Rhine* basin showed that the most important sources of cadmium pollution during the period 1983-87 were industrial point sources and runoff from the land (RIVM/GLOBE, 1992). Emission reduction was implemented in the 1980s, especially at point sources. As a result cadmium levels are presently declining; however, the levels are still high, and additional measures may be needed to further reduce cadmium concentrations.

Copper

Because of its widespread use, copper is both an actual and potential pollutant of the aquatic environment. In catchments with no human activity the river copper concentration is generally lower than 2-5 µg Cu l^{-1} (Nriagu, 1979; Hodson et al. 1979), a level well below the drinking water standard of 1 mg Cu l^{-1}. Such a high concentration is rarely found, and then primarily in connection with mining. That copper is highly toxic to the aquatic biota is well known, copper compounds often being used as insecticides, fungicides, algicides, and molluscides. Its toxicity is generally higher in water with a low mineral content than in water with high alkalinity and hardness. Although the EC directive 78/659 concerning water standards for fish recommends that the copper level be below 40 µg Cu l^{-1} in water with a hardness of 100 mg $CaCO_3$ l^{-1} invertebrates have been reported to be affected by copper levels as low as 10 to 20 µg Cu l^{-1} (Hodson et al. 1979). Since about 20 per cent of the river stations analyzed in this report have copper levels exceeding 10 µg Cu l^{-1}, the aquatic biota may be affected. However, the copper levels rarely exceed 40 µg Cu l^{-1}.

Zinc

Like copper, zinc is also widely used. It is produced in twelve European countries with *the Russian Federation* being the single most important producer (Cammarota, 1980), and with at least 140 zinc mining sites in *Belgium, England, Wales, France, Ireland,* and northern *Spain* (Whitton, 1980). In addition, mining of many other metals also results in zinc being released into the environment. It can thus be assumed that several European rivers are being polluted by zinc.

In natural water unaffected by human activity the zinc concentration is generally below 5 µg Zn l^{-1}. Although human tolerance to zinc is generally high, zinc may be rather poisonous to the aquatic biota. The EC directive 78/659 concerning water standards for fish recommends that zinc levels be below 300 µg Zn l^{-1} in water with a hardness of 100 mg $CaCO_3$ l^{-1} but below 30 µg Zn l^{-1} in water with a hardness of 10 mg $CaCO_3$ l^{-1}. The annual mean zinc concentration exceeded 35 µg Zn l^{-1} at 25 per cent of the river stations analyzed in this report.

Organic micropollutants

Some organic micropollutants (ie. organic compounds) are well known, as are their toxic effects, eg. the pesticide DDT and polychlorinated biphenyls (PCBs). Others are suspected to have effects of various types, including carcinogenic effects, while the environmental effects of others remain to be elucidated.

Traditional monitoring for organic micropollutants in the aquatic environment has focused on organochlorine compounds (eg. DDT), PCBs, and polycyclic aromatic hydrocarbons (PAHs). However, organic micropollutants have rarely been measured on a large-scale basis in national monitoring programmes. In recent years there has been a growing awareness of the problem of aquatic pollution by other dangerous compounds, eg. pesticides. A number of surveys aimed at defining the magnitude of the problem have therefore been undertaken. Nevertheless, it is extremely difficult to quantify the risk presented by organic micropollutants, firstly because the biological effects of most of them are poorly known, and secondly, most of them occur at levels too low to be analytically determined. In addition, the behaviour of many of the compounds in fresh water ie. their adsorption, disintegration, temporal and spatial variability, as well as their bioaccumulation and combined biological effects, are virtually unknown.

Although the use of some of the very toxic organic micropollutants has been either restricted or banned in several European countries during the last 20-30 years, they remain

Photo: POLFOTO

in use in other parts of Europe. In the late 1960s and early 1970s several European countries banned the use of DDT; as a result, there has been a subsequent marked reduction in DDT levels in their surface waters (Olsson & Reutergårdh, 1986; RIVM, 1992). Similarly, since the use of PCBs was restricted in several European countries about 15 years ago, PCB levels in their surface waters have also declined (Olsson & Reutergårdh, 1986; RIVM 1992). High levels of PCBs are still found in some rivers, however (Chevreuil et al. 1987).

Micropollutants in inland surface waters primarily originate from industrial and urban activity and from agriculture. Only few European studies of the pollution sources, their transport pattern and their environmental impact exist. Galassi et al. (1992) studied the toxic effect of organic micropollutants on the zooplankton *Daphnia magna* in the large Italian river *Po* and found that toxicity was highest in May, this being related to the use of pesticides in the river catchment area.

The European aquatic environment is currently exposed to growing numbers and quantities of pesticides as a consequence of the marked increase in the use of pesticides during the last three decades. The level of pesticide is particularly high in rivers and lakes located in intensively agricultivated areas with crops requiring large quantities of water soluble pesticides together with high surface run-off during the pesticide spraying season. Assessment of the environmental risk of pesticides must be based on a combination of studies of their impact on the aquatic biota and model calculations of potential pesticide run-off.

Accidents and leakage from waste disposal sites

Of the many threats posed by organic micropollutants, industrial accidents and leakage from industrial or agricultural storehouses need also to be considered. For example, the well publicized fire at a chemical warehouse in Basel, *Switzerland*, resulted in a significant discharge of organic micropollutants into the *Rhine*; the spill caused fish kill in more than 250 km of the river, and macroinvertebrates were affected more than 600 km downstream (Stumm, 1992).

The leakage of substances from the numerous European waste sites, for example landfill sites, military sites, is another potential source to organic micropollution of inland surface waters.

Radioactivity

Radiation is by its nature potentially harmful to life; it can be lethal at high doses and can cause genetic damage at low doses. Although most radiation stems from natural sources ie. background radiation, various human activities such as nuclear weapons testing and nuclear power production (including fuel mining and enrichment, and final waste disposal), but also scientific and medical uses, have increased the potential for contaminating the aquatic environment with radionuclides.

Nuclear power production and radioactive waste

At present there are more than 200 nuclear power plants in operation in Europe, 68 of which are located in eastern European countries (RIVM/GLOBE, 1992; ATW, 1991). They are usually built close to a major water source, either inland or coastal, the water being needed for cooling purposes. Besides a reduction in flow and thermal pollution of the water, its passage through the nuclear power plant may potentially lead to its contamination with radionuclides.

The levels of radioactivity at 35 locations in 11 large EC rivers which have been monitored since 1984 mainly lie between 0.04-0.4 Bq l^{-1} (EC, 1989). Sparse information about radioactivity in surface waters was obtained from the countries questioned for the present report. However, the information available indicates levels ranging from 0.01 to 0.8 Bq l^{-1}. The highest levels being found in rivers in *the Ukraine* and *the Czech Republic*, and the low-

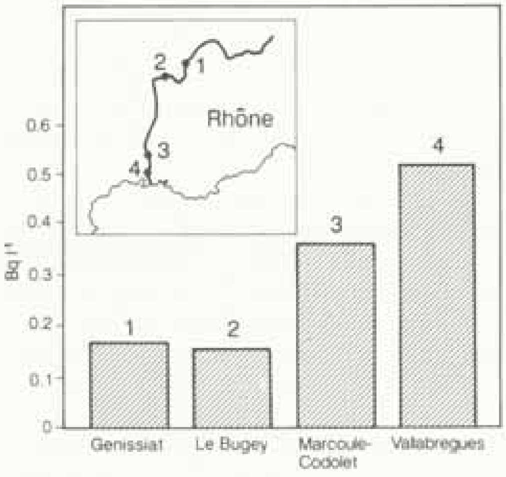


Figure 49:

Annual mean total beta activity in the river Rhône. (Redrawn from EC, 1989).

est levels generally in northern *Finland*. In some rivers, eg. the *Rhône*, increased levels of radioactivity have been recorded in the lower reaches (*Figure 49*), this probably being attributable to discharge from nuclear installations. However, the radiation levels observed are well below those considered of any significance from the point of view of human health (EC, 1989). The possibility of an impact on the aquatic biota may in some cases occur.

Nuclear waste disposal sites are another potential source of contamination of inland surface waters. There have been several reports from eastern European countries of careless handling of radioactive waste products leading to contamination of lakes and rivers.

Accidents

Accidents at Chernobyl in *the Ukraine* and at Three Miles Island in *USA* demonstrate that the possibility of nuclear accidents cannot be excluded, although their potential impact can be reduced. Thus while the damage to the core and the amount of radioactivity released into the building were comparable in both accidents, the fact that the reactor at Three Miles Island was contained prevented the release of radioactive material into the environment; at Chernobyl, in contrast, the reactor was not contained and a large amount of radioactive material escaped (RIVM/GLOBE, 1992). While all reactors in western Europe are contained, many reactors in eastern European countries are neither contained nor comply with western safety standards.

The Chernobyl accident resulted in about 3.5 per cent of the radioactive material in the reactor being released into the atmosphere; fallout spread to many countries, *the Ukraine, Belarus, the Russian Federation, Finland, Sweden, Norway* and Alpine regions being affected most seriously. The year after the accident the highest effective radiation levels recorded in nearby countries were up to 30 per cent greater than background levels (RIVM/GLOBE, 1992).

In the areas affected by the radioactive fallout a part of the radioactive material was washed out in the rivers and lakes. In the rivers *Pripyat* and *Dnepr* situated near the nuclear plant, very high radiation levels were observed in the first days following the accident (approx. 3500 Bq l^{-1}). Within a month the levels decreased by a factor of 100, but high radiation levels can still be observed (Voitsekhovitch et al. 1993). In *Finland*, the southern part was most heavily affected by the nuclear fallout and high radiation levels were observed in the two large rivers draining the area, *Kokemäenjoki* and *Kymijoki* (*Figure 50A*). In the following years the level decreased, but it is still much higher than before the accident. In areas not so heavily affected by the fallout such as the large rivers in northern *Finland* and the rivers near St. Petersburg, the radiation level changed as well after the accident (*Figure 50B*).

The Chernobyl nuclear power plant after the accident in 1986.
Photo: Lehtikuva/POLFOTO

The effect of this fallout on the biota of Swedish rivers and lakes was studied shortly after the accident (Petersen et al. 1986), but no immediate damage to aquatic organisms was

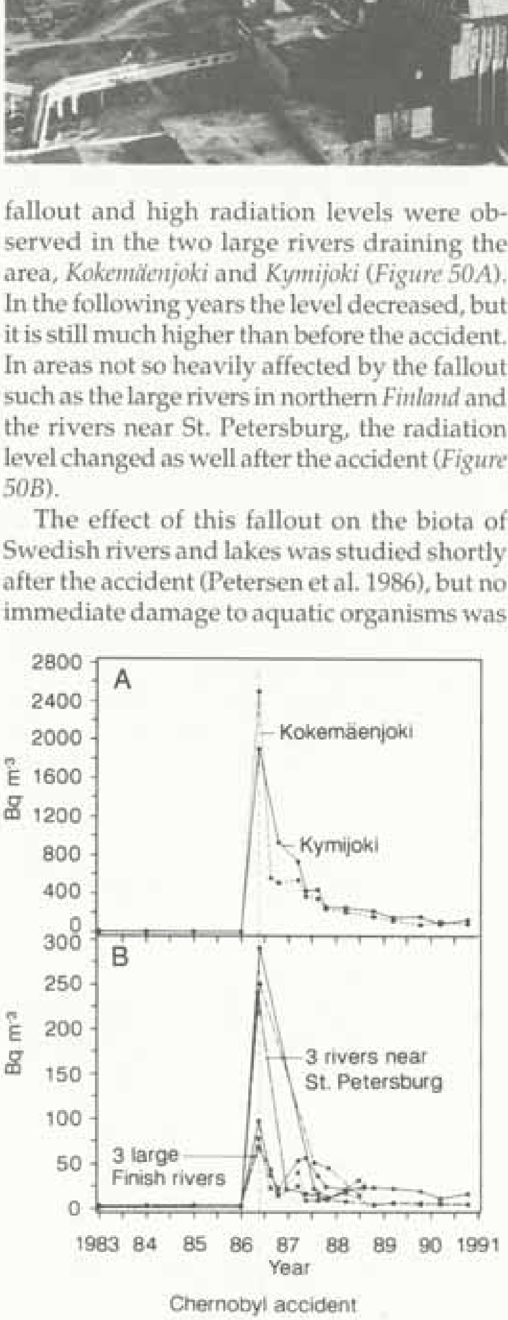


Figure 50: Observations of ^{137}Cs in **A**) two large rivers in southern Finland, and **B**) three rivers running near St. Petersburg and three rivers from northern Finland.
(Finnish rivers from Stuk, 1984-92; Rivers near St. Petersburg from Gavrilov et al. 1989).

found. Nevertheless, the possibility of a long-term biological effect cannot be ruled out, the effects of the increase in background radiation level and the bioaccumulation of radioactivity through the aquatic food chain being unclear.

Other hazards

Pathogens

Inland surface water polluted by faecal discharge from man and animals may transport a variety of human pathogens (pathogenic bacteria and viruses). Pathogens in rivers and lakes are generally observed in the most densely populated areas where domestic and animal excreta are not adequately treated. In Europe, increasing awareness of this pollution problem during the last century resulted in more efficient waste water collection and treatment. In addition water bodies were divided in two categories; those used for waste removal and those used for drinking water. Pathogens in European rivers and lakes no longer pose a general problem for the public water supply.

Salinization

In many dry parts of the world rivers have become saline because of high concentrations of dissolved salts such as fluoride, sodium and chloride. This impairs use of the water for human and livestock consumption, just as it affects water use for irrigation and even industry. Salinization may also impoverish the ecological state of the rivers.

The downstream areas of the river *Volga* and *Don* catchments in the southern part of *the Russian Federation* are very dry and affected by salinization. Salinization has also become a problem in other dry parts of southern Europe, where it is aggravated by the increasing use of water for irrigation since this allows rapid surface water evaporation.

Mining activity, particularly salt, potash, and iron mines as well as ore fields, results in the release to inland surface waters of brine containing high concentrations of dissolved salts. An example is *Poland*, where the daily load to the upstream reaches of river *Wisla* amounts to 7000 tonnes of salt. Several other European rivers, eg. the *Rhine* and the *Elbe*, have also been seriously affected by mining for many years.

Chloride affected rivers are also found in the southern Harz potash mining area in eastern *Germany* (Umweltsbundeamt, 1990) where, concentrations exceeding 30 000 mg Cl l^{-1} have been recorded in the tributaries to the river Saale.

As an example, *Figure 51* shows the development of the chloride concentration in the river *Rhine*. Pollution first became a problem in the 19th century, increased gradually until World War II, and then rose steeply (Wolff, 1987). The high salt content of the *Rhine* water has negatively affected the crops grown by the market gardeners of the Dutch Westland district, and they have fought many legal battles with the potash mining industry concerning compensation for their economic losses (Wolff, 1987).

Figure 51:
Chloride concentration in the Rhine near Lobith.
(Redrawn from van der Weijden & Middelburg, 1989).

4 Plants, fish, birds, and mammals in European freshwater habitats

The presence of characteristic plants, fish, birds, and mammals in or along streams and lakes is an integral part of the experience that these environments provide for the public, not least because many of the freshwater habitats are of importance for recreational purposes.

In the following sections case stories are presented for selected plants, fish, birds, and mammals in order to illustrate the variety of environmental problems that they face. The birds and mammals are among the largest species dependent on freshwater habitats and were chosen for two reasons: firstly because the best data are available for large species; secondly because the greater territorial requirements of large species render them more readily affected by environmental deterioration than small species.

Photo: Benny Gènsbøl/BIOFOTO

Aquatic macrophytes in European fresh waters

Aquatic plants are familiar to most people, mainly because of the widespread ornamental use of tropical species in aquaria. Nevertheless, few people are aware that European fresh waters are home to numerous species of aquatic plants, many of which compare with tropical species when it comes to ornamental beauty and biological characteristics.

Many European surface waters have lost their natural aquatic vegetation in recent years, largely as a result of pollution and eutrophication. Lakes and rivers with a well developed vegetation are therefore rarer than ever, and are becoming even rarer. Thus not only have many aquatic plants become rare, vulnerable or threatened, but some have even become extinct in parts of their natural distribution area. Furthermore, since the submersed vegetation is of major importance to lake and river biological and chemical processes, the ecological stability of many lakes and rivers has decreased dramatically.

The term "aquatic macrophytes" is generally used to denote a very heterogenous group of water plants comprising those that grow permanently submersed (submersed macrophytes), as well as those which grow in or near water, but which have aerial leaves and inflorescenses (emergent macrophytes).

Including those emergent macrophytes that develop distinct submersed forms, there are about 250 species of submersed macrophytes in Europe. True submersed macrophytes number approximately 150 species, including the charophytes. The majority occur both in lakes and in rivers, some are restricted to lakes, and only a few species are restricted to running waters.

Because they are restricted to the aquatic environment, submersed macrophytes are very sensitive to changes and deterioration in water quality. Each species is more or less adapted to a specific type of aquatic habitat as defined by the characteristics of both the water and the sediment. The more specialized a species is to a specific habitat, the more vulnerable it usually is.

All submersed macrophytes are dependent on sufficient light being transmitted through the water to satisfy their photosynthetic requirements. Thus any decrease in light transmission as a consequence of an increased water turbidity will lead to a decrease in the maximum depth at which plants can grow and reproduce, or to a reduction in vegetation density. A change in light conditions may also lead to a change of species composition since species adapted to high light intensity may be ousted by species adapted to low light intensity. When turbidity is extreme, as is already the case in many European lakes and rivers, all submersed macrophytes become eliminated.

In this section characteristic submersed species found in different types of lake and river habitats selected from the EC habitat directive 1992/43/EEC will be presented and discussed. The information about present distribution is partly derived from questionnaires forwarded to all European countries in connection with the preparation of the report "Europe's Environment – The Dobříš Assessment" (1994).

Lakes

In the EC habitat directive 1992/43/EEC, oligotrophic (nutrient poor) lakes have been assigned high priority as aquatic habitats in need of special protection. They range from soft water lakes to hard water lakes and are characterized both by the low nutrient content of their water and by the presence of specific macrophyte communities.

Macrophytes characteristic of oligotrophic soft water lakes

Soft water lakes are characterized by a low concentration of dissolved inorganic carbon (mainly dissolved carbon dioxide) and hence low buffering capacity to acid precipitation. The water is generally slightly acid, with pH in the range 5-6. Most undisturbed soft water lakes have clear water and a high transparency to light. Some soft water lakes are strongly coloured by humic compounds, but are not considered here. Oligotrophic soft water lakes are mainly located in mountain areas with acidic rocks, and in lowland areas with nutrient-poor alluvial soils, primarily sand.

Throughout the European region, characteristic macrophyte associations have been recognized in oligotrophic soft water lakes. Since one of the dominant and most conspicuous species in many of these associations is the water lobelia (*Lobelia dortmanna* L.), many oligotrophic soft water lakes are termed "lobelia lakes". However, the most prominent character species of the typical lobelia lake is in fact the common quillwort (*Isoëtes lacustris* L.). The European oligotrophic soft water lakes have a number of characteristic species (*Box 6*). Few if any lakes contain all the species listed in *Box 6*. Temporary lakes, for example, may only contain one or two species.

Box 6:
Species characteristic of the lobelia lake association.

Awlwort – *Subularia aquatica* (L.) Ascherson

Pillwort – *Pilularia globulifera* L.
(included in the European Red List of Globally Threatened Animals and Plants (United Nations, 1991)

Pipewort – *Eriocaulon aquaticum*

Shoreweed – *Littorella uniflora* (L.) Ascherson

Bulbous rush – *Juncus bulbosus* L.

Water lobelia – *Lobelia dortmanna* L.

Spring quillwort – *Isoëtes echinospora* Durieu

Common quillwort – *Isoëtes lacustris* L.

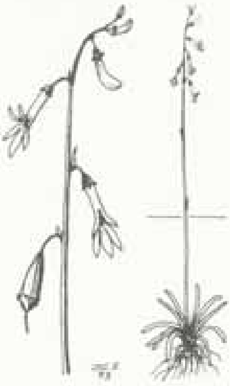
Six-stemmed waterwort – *Elatine hexandra* (Lapierre) DC.

The water lobelia and the common quillwort are perennial and belong to a group of submersed macrophytes usually referred to as rosette plants since their leaves are arranged radially to form a rosette on a very short, vertical rhizome. The latter bears numerous, short and thick roots which play an important role in the uptake of inorganic carbon. As the water in soft water lakes contains little dissolved inorganic carbon, the plants therefore obtain inorganic carbon from the carbon-rich sediment. Thus both the roots and the leaves are rich in air-filled lacunae that facilitate the transport of the carbon dioxide from the roots to the photosynthetic tissue. Rosette plants and the lobelia lake as an ecosystem have been the subject of numerous investigations over the years, (eg. Wium-Andersen, 1971; Søndergaard & Sand-Jensen, 1979; Sand-Jensen & Søndergaard, 1978, 1979), and their biology and habitats are therefore well known.

Water lobelia

Lobelia dortmanna L.

The water lobelia is a typical rosette plant with thick shiny air-filled leaves. In early summer the submersed plants produce long vertical stems which bear pale blue flowers high above the water surface. Pollination and fructification take place in the air and in late summer the ripe seeds drop into the water and germinate. In contrast to the quillworts, the water lobelia is able to survive periods without water cover, eg. in connection with low water levels in dry summers.



Water lobelia (*Lobelia dortmanna* L.)

Habitat
The water lobelia prefers a sediment of sand and fine gravel, but will also grow well on a more muddy bottom.

The water lobelia is mainly found in the upper part of the littoral zone, between the quillwort zone in the deep water, if present, and the shoreweed zone in shallow water, as well as those parts of the shore that are dry in the summer.

Past and present distribution
The water lobelia is mainly distributed in the northwestern part of Europe (*Figure 52*). Information on its distribution and status is incomplete, especially for the eastern part of Europe.

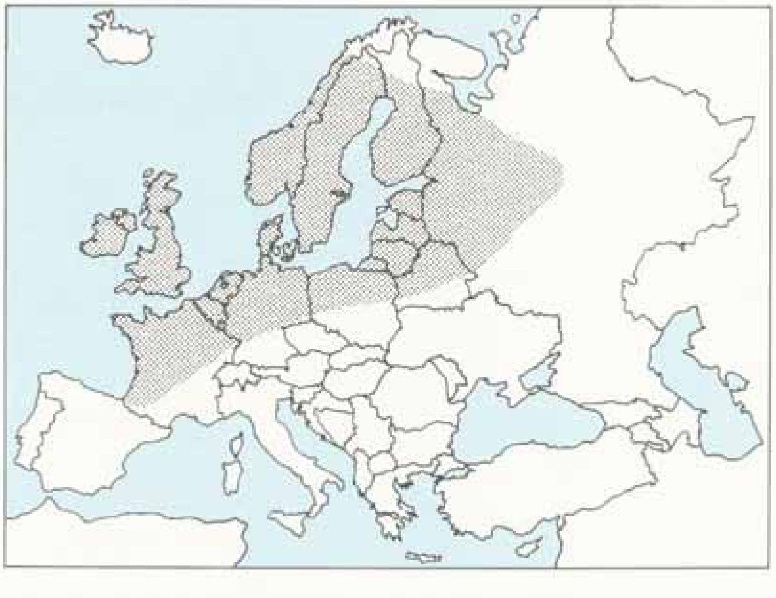


Figure 52:
Distribution area of the water lobelia.
(Drawn from data from the questionnaires and from data in Casper & Krausch, 1981. The boundaries of the distribution area are somewhat uncertain and should not be used for future reference.)

Its distribution area as a whole appears not to have changed much this century. Nevertheless, it is well documented that the water lobelia has suffered a severe decline in the main part of its distribution area, and has become almost extinct in some parts.

The distribution area of the water lobelia has always centred around Scandinavia and the British Isles, and it is currently characterized as common in *Norway*, *Sweden*, *Finland* and parts of *the United Kingdom*. It was common or fairly common in *Denmark* and the northwestern parts of *Germany* in the first half of this century, but has always been more rare in the rest of its distribution area. It has now disappeared from many habitats in the continental parts of Europe, currently being classified as rare, vulnerable, threatened or even as extinct in many areas. The water lobelia is not included in the European Red List (United Nations, 1991), but appears in a number of national red lists.

Common quillwort
(*Isoëtes lacustris* L.)

Common quillwort

Isoëtes lacustris L.

The common quillwort is one of the few ferns that grow submersed. It produces numerous stiff, 5-15 cm long dark green leaves. The spores are located at the base of the leaves and when they are ripe the leaves break off, and are carried away by the current, thereby aiding spore dispersal.

In contrast to the water lobelia, the common quillwort cannot survive on summerdry shores, and is therefore usually found well below the summer water level. It can grow at depths of [illegible]-5 meters, sometimes even deeper if the water is very clear. The common quillwort undergoes its full life cycle in the water and the plants can probably become more than 10 years old.

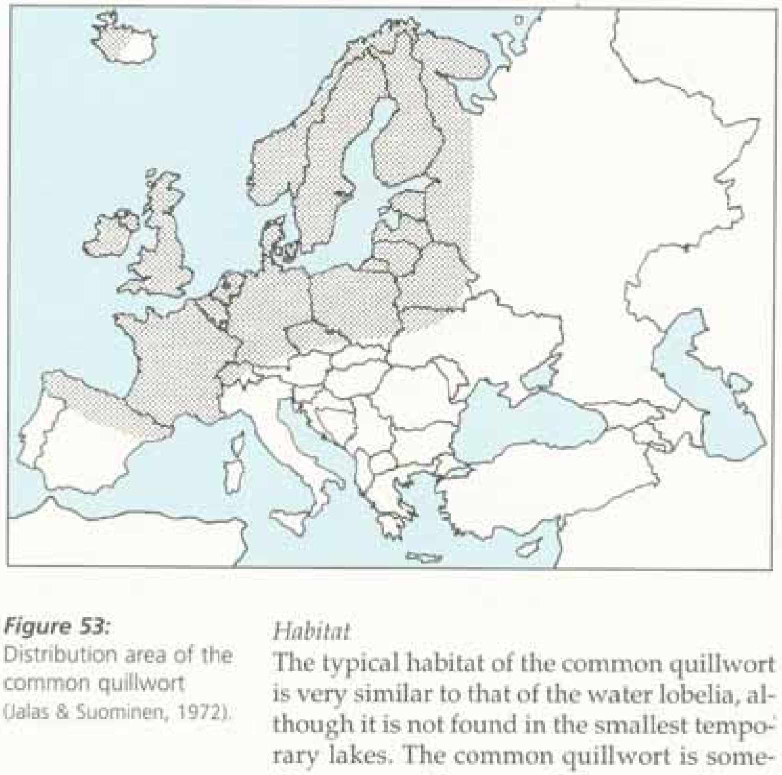


Figure 53:
Distribution area of the common quillwort (Jalas & Suominen, 1972).

Habitat

The typical habitat of the common quillwort is very similar to that of the water lobelia, although it is not found in the smallest temporary lakes. The common quillwort is sometimes present in areas of the upper littoral zone lakes where the presence of water lobelia is precluded for example by the bottom morphology or sediment type.

Past and present distribution

The distribution area of the common quillwort is very similar to that of the water lobelia, but extends further to the north and east (*Figure 53*). Its distribution area seems not to have changed this century, but its status has changed in major parts of its distribution area. As it was at the beginning of the century, the common quillwort is currently common in *Sweden*, *Norway*, *Finland* and the western parts of *the Russian Federation*, as well as in the western and northern parts of *the United Kingdom* and *Ireland*. In the northwestern part of its distribution area, which also includes the southern part of *Greenland*, it is still rare, its status being unchanged. In the central and southern part of Europe it extends further to the east than the water lobelia. While already rare there in the first half of the century, it has now become even more rare, and has actually disappeared from many habitats. The common quillwort is not included in the European Red List (United Nations, 1991), but appears in a number of national red lists.

Status of the lobelia lake species

Based on the findings of questionnaires the following conclusions can be drawn concerning the general status of lobelia lake species in Europe.

1. Of species classified as "common" prior to 1950, the status of 65 per cent is unchanged, while 35 per cent have now become either "rare but not threatened" or "vulnerable or endangered".

2. Of the species classified as "rare but not threatened" prior to 1950, the status of 40 per cent is unchanged, while 50 per cent have now become "vulnerable or endangered", 4 per cent have become "extinct" and 6 per cent have become "common".
3. Of the species classified as "vulnerable or endangered" prior to 1950, the status of 86 per cent is unchanged, while that of 14 per cent is unclear.

With the reservation that some degree of uncertainty is always associated with surveys of this type, the findings illustrate that the lobelia lake species have declined considerably during the present century.

Threats and protection measures

Oligotrophic soft water lakes are the natural type of lake on nutrient poor soil. The catchment area of lobelia lakes is typically covered by heath and coniferous forrest. The drastic decline in the number of undisturbed lobelia lakes is mainly attributable to a change in land use in the catchment areas, as is the deterioration in their water quality.

If the catchment area is used for agriculture or forestry, or if the human population in the catchment areas grows, an increase in lake water nutrient levels usually follows. This typically results in an increase in phytoplankton and epiphytic algal, a decrease in light transmission and a subsequent decrease in the depth distribution of lobelia lake species. When nutrient loading is high the water lobelia and the common quillwort have in many cases been completely eliminated, as too have other members of the oligotrophic soft water lake associations. The common quillwort and other of the deeper growing species are particularly vulnerable to a reduction in light transmission, and therefore among the first species to disappear when lobelia lakes become eutrophic.

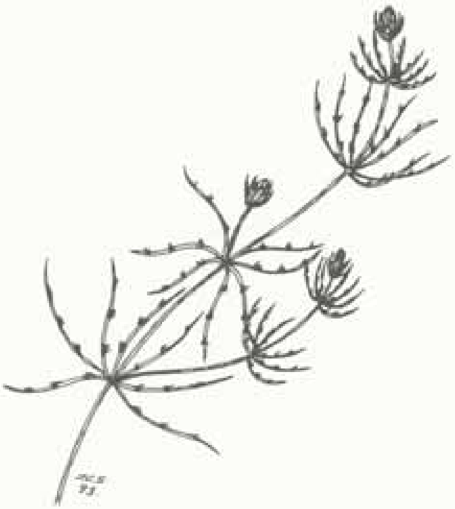
In *Norway*, *Sweden*, and *Scotland*, acidification is a major threat to oligotrophic soft water lakes, many of which have become so acid (pH <4) during the present century that the indigenous vegetation has been replaced by sphagnum mosses or the lakes have become devoid of vegetation (eg. Grahn et al. 1974; Grahn & Hultberg, 1974; Grahn, 1977; Hultberg & Grahn, 1975).

It is generally accepted that lobelia lakes and other types of oligotrophic soft water lakes are threatened by various types of human activity, and national and international programmes aimed at protecting the most vulnerable habitats have therefore been established (1992/43/EEC). In spite of this, however, the number of lobelia lakes is still decreasing. The situation is in many ways comparable to that in a tropical rain forest; in both cases most of the nutrients are permanently retained in the biomass and even minor disturbances can cause severe deterioration in ecological stability. Furthermore, like the rain forest, once lobelia lakes are destroyed they need a very long time to recover, if recovery is at all possible.

Future conservation of lobelia lakes must therefore be based on giving the remaining lobelia lakes maximum protection from being polluted with nutrients. It is very important that their catchment areas remain uncultivated, and that any tributaries are kept free of pollution. The threat from acid precipitation, can only be reduced by ensuring that international programmes for reducing the emission of acid components are fully implemented as soon as possible.

Macrophytes characteristic of oligotrophic hard water lakes

Hard water lakes mainly differ from soft water lakes in having a much higher concentration of dissolved inorganic carbon, primarily hydrogen carbonate, and a higher pH, in the range 7-9. They generally have a high buffering capacity to acid components. Oligotrophic hard water lakes are mainly located in mountain areas with limestone, or in lowland areas where the soil consists of chalk and lime or has a high content of alkaline components.



Chara vulgaris L.

The oligotrophic hard water lakes are generally habitat for only a few plant species.

In one group of alkaline lakes charophytes are the dominant characteristic macrophyte group. These are among the largest and most complex of the green algae, and can grow at depths of as much as 20 meters (Moore, 1986). In contrast to other green algae, eg. filamentous algae, the charophytes have a distinct resemblance to higher plants. They often form dense carpets in which few if any other macrophytes are present. Charophyte lakes are included as a lake type in the EC habitat directive 1992/43/EEC.

Most of the charophyte species that grow in very alkaline lakes belong to the genus *Chara*. Common species are *Chara tomentosa* L., several varieties of *Chara vulgaris* L. and *Chara hispida* L. *Nitellopsis obtusa* also grows primarily in alkaline lakes with high pH.

Typical charophyte lakes vary in size from small temporary ponds to large, very deep lakes. Charophytes that inhabit temporary lakes are annuals which survive the dry period as oospores (equivalent to seeds), while those that inhabit deep lakes, are often perennials. Many charophyte species also occur in other types of lake, and some charophyte species do not even grow well in very alkaline lakes.

Past and present distribution

The distribution of charophytes has always been less well known than that of most other macrophytes. Nevertheless, there is no doubt that charophyte communities have previously been widespread in Europe, particularly in regions with calcareous soil, and that they too have declined considerably during the present century. Although it has been stated that the charophytes are particularly sensitive to high concentrations of phosphorus (Forsberg, 1965), recent studies indicate that the major reason for the decline of charophytes is the reduction of lake water transparency (Blindow, 1992).

Threats and protection measures

The hard water lakes are also threatened by human activity and nutrient loading. Given that charophytes grow at depths of 10-20 meters, even a minor increase in phytoplankton biomass will reduce light availability and thereby reduce their depth distribution. In the most nutrient polluted lakes the charophytes have been totally eliminated, oospores in the sediment being the only evidence of their former presence.

The charophytes are poorly known, and they do not appear in any national or international red lists. This is probably the main reason why charophyte lakes have not been included in national and international conservation programmes until recently. Typical charophyte lakes are now included in the EC habitat directive 1992/43/EEC. Their conservation requires that they be kept free of external nutrient loading. Optimal protection of charophyte lakes can only be achieved if their catchment areas are kept free from agriculture, forestry and other human activities that might deteriorate water quality.

Rivers

The rivers of Europe are of great importance as habitats for many macrophytes. Due to the heterogeneous nature of rivers, the species associations of rivers are often less well defined than are many associations in lakes. Furthermore, river macrophyte communities are in many ways much more dynamic than those of lakes, with a changing species composition and abundance. In many cases, however, the natural dynamics has been completely overshadowed as a result of mechanical and chemical weed control, channelization, and waste water discharge. A number of different types of river habitats have recently been included in the EC habitat directive 1992/43/EEC, including lowland rivers.

River water-dropwort

Oenanthe fluviatilis (Bab.) Coleman

The river water-dropwort is an umbelliferous perennial with a thick rhizome. It grows in two forms depending on the nature of the river. In fast flowing or deep rivers it grows permanently submersed and produces only

River water-dropwort
(*Oenanthe fluviatilis* (Bab.) Coleman)

finely divided leaves on short, sterile stems, a form which renders it easily confused with other species, eg. *Batrachium* spp. In calm or more shallow waters it usually produces tall, emergent stems with less divided leaves and white flowers. The stems can reach heights of more than one meter, thus making flowering specimens very conspicuous. During winter both forms are usually submersed with few leaves.

Habitat

The river water-dropwort is a river plant, growing mostly in medium sized unpolluted rivers of both alkaline and soft water. It does occur in a few standing water localities. It grows on different types of sediment, but seems to prefer sand and gravel.

Other species and genera characteristic of this type of habitat are *Batrachium* spp., *Callitriche* spp., *Berula erecta* (Hudson) Coville, *Myriophyllum alterniflorum* DC. and *Potamogeton* spp.

Past and present distribution

The river water-dropwort is a typically atlantic species that has always been restricted to northwestern Europe and which is currently only found in the British Isles and *Denmark* (*Figure 54*). Within its distribution area in the British Isles, particularly in Ireland, it can be locally quite common. Thus even though the number of habitats has declined the species is still classified as common. In *Denmark* it was locally quite common in the first half of this century in several of the major western rivers (Løjtnant & Worsøe, 1993). Today it mainly occurs in the river Skjern Å system, and the populations may even be increasing. The species is not yet included in the European Red List (United Nations, 1991).

The river water-dropwort is sensitive to channelization, dredging and other types of mechanical intervention. It also seems to be sensitive to increases in water turbidity. The reason for its continual decline may therefore be that many of the rivers within its distribution area are regularly subjected to weed control and dredging, and/or are polluted.

No programme yet exists to specifically protect the river water-dropwort. However, a ban on weed cutting and dredging in the river Skjern Å in *Denmark* has increased the distribution of the plant significantly. Furthermore, several other species have also benefitted and the river vegetation on the whole has become more diverse and stable.

Figure 54:

Distribution area of the river water-dropwort

(Drawn from data from the questionnaires and from Casper & Krausch, 1981. The boundaries of the distribution area are somewhat uncertain and should not be used for future reference.)

River crowfoot

Batrachium fluitans (Lamarck) Vimmer

The river crowfoot is one of the many species of the crowfoot genus (*Batrachium*), a large number of which occur in both standing and running waters. The river crowfoot is a perennial and produces only submersed, finely divided leaves on stems up to several meters long. In early summer its conspicuous white flowers are borne above the water surface by leafless peduncles. In the winter period growth is slow, and the species survives with short stems bearing leaves.

Habitat

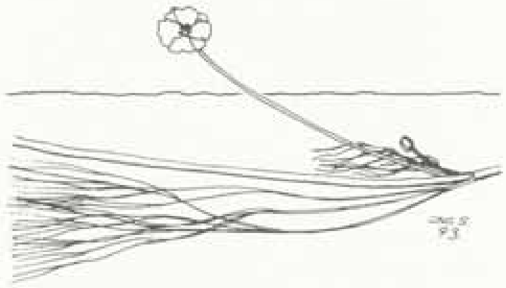
The typical habitats of the river crowfoot are small to medium sized rivers with moderate to swift flow, clear water, low to moderately high nutrient levels and more or less alkaline water. The preferred sediment type is coarse sand, gravel and stones.

The river crowfoot often occurs together with *Callitriche* spp., and *Berula erecta* (Hudson) Coville.

Past and present distribution

The distribution area of the river crowfoot is centred in western and central Europe (*Figure 55*). While it seems to have remained largely unchanged during the present century, the status of the river crowfoot has changed for the worse. In the eastern parts of its distribution area, where it has always been rare, it has now become vulnerable or even endangered.

However, in the central and western parts of its distribution area, it is still common in many areas, and in some cases it is even the characteristic species of clear water rivers with swift flow. The river crowfoot is not included in the European Red List (United Nations, 1991).



River crowfoot
(*Batrachium fluitans*
(Lamarck) Vimmer)

The river crowfoot is sensitive to pollution with organic matter and, being rather intolerant to shade, is also very sensitive to increases in water turbidity. These two factors are partially responsible for its decline, although channelization and the removal of riffles are also of importance. In many ways the river crowfoot is therefore a good indicator species for undisturbed, clean rivers.

Threats and protection measures
Undisturbed lowland rivers, some of which are habitats of the river crowfoot, are included in the EC habitat directive 1992/43/EEC. This type of habitat, and hence the river crowfoot and most associated species, are not acutely endangered. However, the number of undisturbed rivers is continually decreasing, and this type of habitat therefore needs to be protected from pollution and from channelization and environmentally inappropriate maintenance.

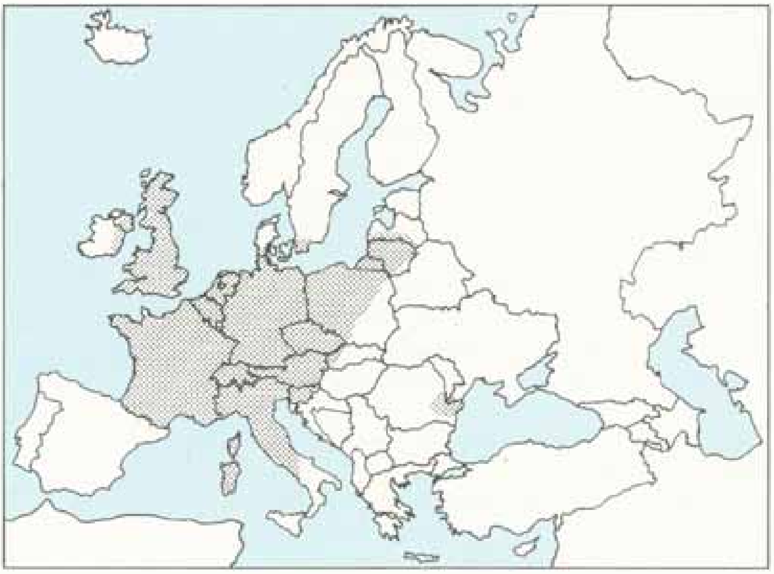


***Figure 55*:**
Distribution area of the river crowfoot
(Jalas & Suominen, 1972).

Considerable attention has been paid to reduce nutrient loading of rivers. As a result, water quality in a number of European rivers has already been improved, especially through the improvement of sewage treatment. In addition, a better understanding of the importance of the macrophyte vegetation to river quality has led to the implementation of more environmentally appropriate river maintenance practices. Together, improved water quality and more appropriate river maintenance will eventually lead to a much more diverse and well developed river vegetation able to accommodate rare and vulnerable species. In contrast to most lakes, rivers are generally able to recover rapidly. The river crowfoot therefore appears to be a well protected species in Europe.

Water-plantain
Luronium natans (L.) Raf.

In considering aquatic macrophytes one species deserves special mention – the water-plantain. In contrast to most other European macrophytes, the water-plantain only occurs in a limited area of western Europe that is also its global distribution area. As both the European Red List of Globally Threatened Plants (United Nations, 1991) and the EC habitat directive 1992/43/EEC classify it a "rare and threatened" species in most parts of its distribution area, the European countries have a special responsibility to protect the species from extinction.

The water-plantain is a perennial species found in both standing and running waters, mainly of the oligotrophic soft water type. It produces linear submersed leaves in early spring, but in early summer these are partly or wholly replaced by small, oval floating leaves, among which the white flowers are carried above the water surface on thin and fragile peduncles. In deep waters it only produces linear leaves and does not flower. It has considerable potential for vegetative dispersal by means of stolons (offshoots) and under favourable conditions can therefore form large and dense stands. The numerous stolons also give the water-plantain considerable potential for downstream dispersal. In contrast, however, the water-plantain generally seems to have little capacity to disperse from one river to another.

Photo: Ib Trap-Lund/BIOFOTO

Habitat

The typical habitats of the water-plantain are reported to be shallow oligotrophic or slightly eutrophic soft waters, ranging from the littoral zone of subtypes of the lobelia lake, to rivers and canals, and to small water bodies of various kinds (Casper & Krausch, 1981). The preferred sediment type is sand, but it also grows well in sediments with a high content of organic matter.

In contrast to its habitats in most other countries, its recent habitat in *Denmark* is drainage canals. Although there are thousands of such canals, it is only found in three, which are 3-15 meters in width. In the largest the bottom area covered by water-plantain currently amounts to several thousand square metres.

Past and present distribution

The water-plantain is primarily a west European species (*Figure 56*). Although still present in parts of *the Russian Federation* and some of the southeastern countries at the beginning of this century, it is now reported to be extinct in that part of Europe. It has always been rare in most of its distribution area, but the situation has deteriorated further and it has therefore been classified by the International Union for Conservation of Nature and National Resources (IUCN) as vulnerable in all parts of its distribution area (United Nations, 1991).

Threats and protection measures

As with most other aquatic plants, eutrophication and the resultant reduction in water transparency seems to be the most important reason for its decline in standing waters, while morphological changes in its habitats caused by canalization, dredging and draining seem to be more important in running waters. However, as its three primary habitats in *Denmark* are all canals regularly subjected to mechanical weed control and dredging, the real cause of its decline in rivers seems to be open to question.

In *Denmark*, the international classification of the water-plantain as "vulnerable" has led to its protection by law, it now being prohibited to remove it from any of its habitats. However, the habitats are not protected.

Water-plantain (*Luronium natans* (L.) Raf.)

Because the water-plantain is so rare, it is important that its remaining habitats be registered and described with respect to environmental quality and threats so that an appropriate protection program can be set up. If its continual decline is not stopped soon, the water-plantain will become extinct in large parts of its present distribution area.

Figure 56: Distribution area of the water-plantain (United Nations, 1991).

The aquatic macrophytes in Europe – future perspectives

Aquatic submersed macrophytes are vulnerable as a group because of the widespread use of their habitats as recipient waters for domestic and industrial waste, and because of nutrient loading from agriculture.

It is now realized that both standing and running waters need protection. In most cases, good water quality and well-developed and diverse macrophyte communities go hand in hand.

While the biology and ecology of European aquatic macrophytes are generally well known, knowledge of their previous and present distribution is much less detailed, and in many cases insufficient. Even though *Denmark* is one of the smallest countries with a long tradition of botanical investigation, habitats of rare, vulnerable and endangered macrophytes are still being discovered. This indicates that only through very intensive and detailed investigation will it be possible to obtain a realistic and true picture of species distribution and habitats that can form the basis for classifying the species in the national and international red lists. A further problem is that taxonomical identification of submersed macrophytes is difficult because many of them hybridize, and occur in atypical forms, or can only be identified when in flower or bearing ripe fruit. Therefore, the aquatic vegetation is generally less well described than the terrestrial vegetation.

Only few species of aquatic macrophytes are currently included in the international red lists, and less than 10 aquatic macrophytes are included in the EC habitat directive (1992/43/EEC) and in The European Red List (United Nations, 1991). None of the red lists include the charophytes, many of which are known to be very sensitive to environmental changes. However, many of the national red lists include an even greater number of aquatic macrophytes, which reflects the regional differences in the status of macrophyte species.

The low number of red listed macrophytes should not be taken as indicating that only few species are threatened in European fresh waters - rather it reflects the fact that aquatic macrophytes are insufficiently described.

There is therefore considerable need for detailed investigation of the aquatic vegetation in all parts of Europe, elaboration of detailed identification keys and further studies of the more complex taxons, eg. the crowfoots (*Batrachium* spp.). Similarly, there is considerable need for conservation programmes aimed primarily at the most undisturbed and sensitive habitats and those of red listed species, but also aimed at ensuring optimal floral diversity in general. Since the necessary protective measures are generally well known, the main hindrance to their implementation is financial in character. However, increasing appreciation of the need to act against eutrophication and pollution provides hope that the overall decline in aquatic macrophytes will be stopped. In fact, indications of improved water quality have already been seen in many parts of Europe.

Freshwater fish

Freshwater fish are a conspicuous element of European freshwater environments, there being 250 species in all, 28 of which have been introduced. Nevertheless, the European fish fauna is relatively poor compared to that of many other continents, eg. Africa, which has about 1800 freshwater fish species. This not withstanding, several of the European freshwater fish species are important for the commercial fishery and an even greater number are important for the recreational or sports fishing.

The number of species in a river system generally increases with increasing watershed area and decreasing latitude. Thus central and southern European rivers have a greater number of species than northern European rivers, the Volga and the Danube having for example 60-70 species, ie. about a quarter of the total European fish fauna.

Both sedentary and migratory fish populations are found, the latter migrating both between marine areas and fresh waters (33 species) and between streams and lakes (13 species). A few species have both sedentary and migratory populations. Each species has its own environmental demands, water current being an important factor; thus 107 of the species or about half of all sedentary species only inhabit rivers, 24 species only inhabit lakes, and 81 species inhabit both rivers and lakes.

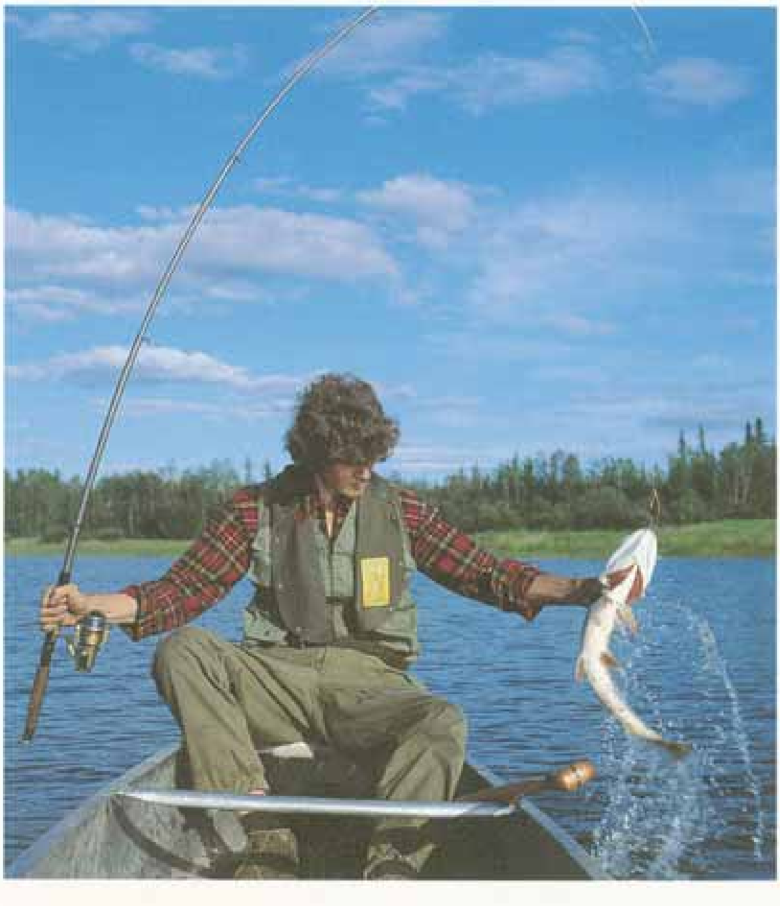
Lake fish populations play an important role in regulating lake trophic structure. In oligotrophic lakes the fish population has a high proportion of piscivorous fish and these are able to control the number of planktivorous fish. However, in eutrophic and hence opaque lakes, the piscivorous fish are unable to control the planktivorous fish which can then efficiently graze the zooplankton and thereby reinforce the effects of eutrophication. Because of their long life span, planktivorous fish are even able to keep the zooplankton populations depressed many years after a reduction in nutrient loading, thus delaying the recovery process significantly.

European freshwater fish populations are jeopardized by many types of environmental deterioration. Eutrophication of lakes has already been mentioned. In many rivers oxygen depletion and high concentrations of ammonia and other toxic substances have significantly reduced fish populations and channelization, maintenance activities and increased sediment transport have destroyed spawning grounds and nursery areas. Similarly, the establishment of dams and weirs has reduced the access of migratory fish to large areas of potential spawning grounds and has fragmented the populations of many sedentary species. Overfishing is a major problem in the case of many commercially interesting species, especially those that spawn at high age and large size.

On a global scale the loss of animal species is occurring at a rate faster than ever previously recorded. The International Union for Conservation of Nature and National Resources (IUCN) has classified animals and plants into global status categories that indicate the degree to which a species is threatened globally. In Europe, 11 freshwater species of fish are classified as globally endangered, 6 species as vulnerable and 3 species as rare. In the Bern Convention 122 species of freshwater fish are now included.

The status for some characteristic species is described below, main emphasis having been placed on well-known and mostly migratory fish species since these are affected by

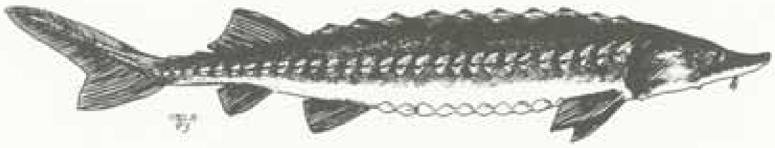
Photo: Peter Bang/BIOFOTO



the deterioration of several environments (rivers, lakes, marine areas), by physical obstacles that prevent their migration, as well as by overfishing.

Atlantic sturgeon

Acipenser sturio L.



Atlantic sturgeon (*Acipenser sturio* L.)

Characteristics and biology

The Atlantic sturgeon is one of nine species of this family present in Europe. They are primitive fish with a very characteristic appearance and may become very old and large, the females having a longer life span and greater size than the males. Although there are reports of a 42 year old female sturgeon from the river Garonne measuring 2.55 m and a 48 year specimen from the Staraya Ladoga archaeological site (7th-10th century) measuring 3.6 m (Holčík et al. 1989), sturgeon rarely exceed 2 m at present.

The Atlantic sturgeon spends most of its time in littoral marine areas, only migrating into rivers to spawn when mature, the males at 7-13 years and the females at 8-18 years. Migratory distances of 800-1000 km have been recorded, but the normal distance is about 100 km. (Holčík et al. 1989). The sturgeon easily passes rapids and may even jump like salmon. Spawning takes place in reaches with a swift current, a substratum of rocks and pebbles, and a depth of 2-10 m. The spent fish immediately return to the sea. The juvenile sturgeon stay in the rivers for 2-4 years feeding on benthic invertebrates and then migrate to the sea. An exception is the sturgeon population in lake Ladoshskoye which does not migrate to the sea, but remains confined to freshwater.

***Figure 57*:** Distribution of the Atlantic sturgeon around Europe. (Redrawn from Holčík et al. 1989).

Exploitation

Sturgeons have been exploited by man for at least 10 000 years, as judged from archaeological remains. The economic importance of the species was based on the use of its flesh for food, its air bladder for making isinglass and its eggs for caviar. Eggs constitute about 20 per cent of the total weight of a migrating female. The total annual world catch of sturgeon early this century is estimated to be 150-200 t, and that of the eggs about 10 t (Holčík et al. 1989). Today the sturgeon is only caught commercially for caviar.

Past and present distribution

Early this century the Atlantic sturgeon was widely distributed along the coastline of Europe from the North Cape, *the United Kingdom* through the Mediterranean Sea to the Black Sea and spawning took place in all major European river systems. It is still widespread in the sea today, but in very reduced numbers (*Figure 57*). In the Atlantic basin there is a successful population spawning in the river Garonne (Castelnaud et al. 1990). The population in the Rioni basin in the Black Sea was commercially important in the 1940s and 1950s, but has now declined to about 300 specimens in the Russian part of the Black Sea (Holčík et al. 1989).

Threats and protection measures

The Atlantic sturgeon is considered threatened by extinction and IUCN has assigned it the status of a globally endangered species. The main reason for the dramatic decline of the species is undoubtedly overfishing, sturgeon being especially sensitive to commercial fishery because they do not mature until the age of at least 7. Hence their decline is closely linked to the development of trawling at the end of the 19th century. Additional reasons for their decline include pollution-induced deterioration of water quality, the establishment of physical barriers that prevent their upstream migration, and the deterioration of their spawning grounds. In the case of the river Garonne population, illegal or accidental catches at sea also pose a threat (Rochard et al. 1990).

Protection measures implemented in *France* have included a minimum catch size (14 cm in 1890, 1.5 m from 1923-81), a limited fishing season since 1939 and total protection since 1982 (Rochard et al. 1990). In *Spain* sturgeon fishery has been forbidden since 1983. Sturgeon is now cultured in *France* and several other countries, and a restoration programme to save the species has been proposed by Elvira et al. (1991). If this programme is to be successful, however, it should be expanded internationally, and should include large-scale restocking, the securing of migratory pathways, the protection of spawning grounds, and a complete ban on fishery.

Danube salmon

Hucho hucho (L.)

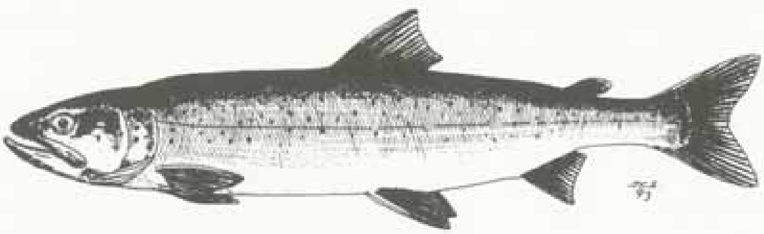
Characteristics and biology

The Danube salmon is one of the largest freshwater fish in Europe and may reach a length of 1.8 m and a weight of 70 kg. The mature male can have a characteristic copper hue that has given it the names "Rotfish" and "Rothuchen" in *Austria* and *Germany*. It is exclusively found in fresh water, being a riverine species that only inhabits oxygen rich streams (>8 mg $O_2\ l^{-1}$) with summer temperature below 20 °C (Holčík, 1990). It is territorial and prefers deep pools, with large specimens occupying the head of the pool with smaller specimens residing further back.

The Danube salmon spawns for the first time at an age of 3-5 years, spawning taking place in March-April, when the snow melts in the mountains. It only migrates 10-25 km, the spawning grounds being stream reaches with a substratum of gravel or coarse sand and a depth of 30-60 cm. The eggs are buried in the substratum at depth of 10-30 cm and are dependent on a continuous flow of oxygen rich water. Early in life the young salmon feed on small drifting organisms while later they feed on benthic invertebrates. Larger Danube salmon feed mainly on fish, but may also take other vertebrates.

Exploitation

The Danube salmon is still netted commercially, but is today mainly considered a sports fish. It is the most popular salmonid species in its area of distribution and is highly appreciated by anglers as a trophy species.



Danube salmon (*Hucho hucho* (L.))

Past and present distribution

The Danube salmon is endemic in the Danube catchment area and historical records show that it used to be common in almost all medium and large rivers in the system. Its area of distribution formerly covered about 11 100 stream kilometres (Holčík, 1990), but has decreased since the turn of the century, especially after World War II. Today the Danube salmon is relatively common in 33 per cent of its former area of distribution, and is rare in a further 26 per cent (*Figure 58*). Furthermore, the present population is estimated to be 5-10 per cent of its previous size (Holčík et al. 1988). Artificial stocking in rivers outside the Danube watershed has been undertaken, but with only limited success.

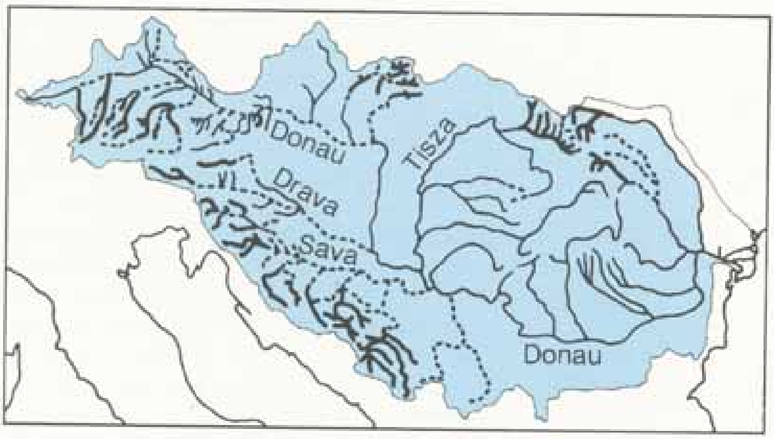


Figure 58: Distribution of the Danube salmon in Europe.
(Redrawn from Holčík et al. 1988).

Threats and protection measures

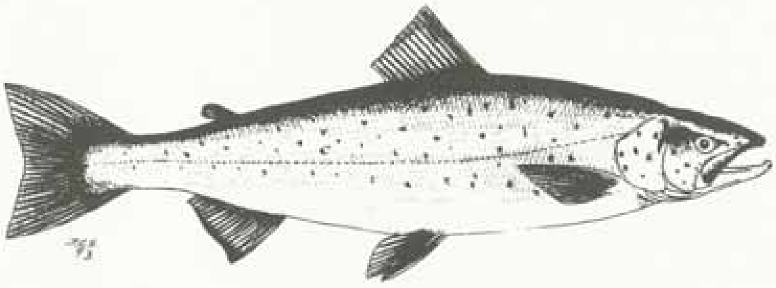
The main reason for the drastic decline of the Danube salmon is the physical destruction of its habitat as a result of channelization, the construction of dams and siltation of spawning grounds. However, poor water quality due to the discharge of industrial and municipal waste water, pesticides, and nutrients has also played an important role. Overfishing is currently considered a secondary threat to the Danube salmon (Holčík, 1990); the measures taken to minimize this factor include restrictive bag limits, a closed season and a minimum catch size (usually 70 cm).

The only river in which the Danube salmon is fully protected is the 21 km long section of the river Turiec in *Slovakia*.

The Danube salmon has been assigned the status of a globally endangered species by IUCN. Its future depends mainly on improved water quality and habitat reestablishment, but it may be temporarily supported by an increased stocking scheme which also involves non-inhabited tributaries.

Atlantic salmon

Salmo salar L.



Atlantic salmon (*Salmo salar* L.)

Characteristics and biology

The Atlantic salmon has the characteristic torpedo-shaped body of a good swimmer and is able to pass dams up to 3 m high while migrating. The usual maximum size is a length of about 1.5 m and a weight of about 35 kg, the heaviest salmon caught having weighed 46.7 kg. Old males may develop an enormous facial hook during the breeding season.

The Atlantic salmon is usually a migratory species that inhabits the open sea but migrates into rivers to spawn. Exclusively freshwater populations are known to exist in *Norway, Sweden, Finland*, and *the Russian Federation* (Kazakov, 1992), but these are exceptions.

Atlantic salmon feed mainly on herring and other fish while in the open sea, but have no regular feeding habits when migrating. They spawn in 0.6-1.0 m deep gravel streams, the eggs being buried in the gravel. After spawning the salmon try to return to the sea, but many males die from exhaustion. After hatching the young salmon stay in the river for 2-3 years, feeding on benthic invertebrates and terrestrial insects, and then leave for the sea. After a further 1-4 years they return to their natal river to spawn.

Exploitation

The Atlantic salmon is one of the most valued of all edible fish. The annual catch in Europe is about 6000 tonnes, worth 30-40 mill. ECU, and marine salmon farming has increased significantly in recent years. The Atlantic salmon is also highly appreciated as a sports fish and in regions with popular salmon rivers the income from tourism associated with sports fishing can be significant.

Past and present distribution

The Atlantic salmon is native to the North Atlantic region, and its area of distribution in Europe once included *Iceland*, northern *Norway*, and the Russian river Pechora in the north down to *Portugal* in the south. It has now disappeared from major rivers in many European countries, however. Thus whereas the Rhine was probably the most productive salmon river in Europe in the 19th century, more than 116 000 salmon from the Rhine having been sold in 1895, the population declined thereafter and the Atlantic salmon became extinct in the Rhine in 1957. In recent years the salmon has returned to a number of European rivers including the Rhine, mainly as a result of the large-scale stocking of artificially reared fish, combined with improvements in water quality.

Threats and protection measures

The disappearance of the Atlantic salmon from so many rivers is attributable to a number of factors. Numerous dams now effectively prevent the upstream migration of mature salmon to their spawning grounds and channelization of rivers has decreased the number of spawning grounds and nursery areas available. Poor water quality and eutrophication due to the discharge of industrial and municipal waste water, pesticides and nutrients has also played an important role. In Scandinavia the acidification of surface waters by acid rain has been the most important factor, the loss of smolt due to acidification having been estimated to be 0.6-1.2 million in *Norway* in 1988 (Anon., 1989). Overfishing has also played a role since the 1960s, following the development of high sea salmon fishery using drift nets and longlines.

An important measure to improve salmon populations include improving the water quality and reestablishing access to previous spawning grounds. These measures are supported by large scale stocking schemes whereby more than 38 million juvenile salmon are annually released into rivers in the North Atlantic region (Kennedy, 1988). Regulation of commercial salmon fishery would further support these measures. The Atlantic salmon has great public interest and the results of the protection measures are becoming apparent as salmon are returning to major European rivers such as the Thames and the Rhine.

Houting

Coregonus oxyrinchus (L.)

Characteristics and biology

The houting belongs to the White-fish family and has a very characteristic appearance with the head protruding into a conical snout. Its maximum length is 40-60 cm and its maximum weight 2-4 kg. It is a marine fish and only migrates into rivers in the spawning season. Although it is said to have ascended the Rhine as far as Strasbourg, its usual migratory distance is less than that of the Atlantic salmon. The houting migrates in shoals and spawns on sandy bottoms. After spawning the adults return to the sea. After hatching the young houting drift out to the sea with the river current.

Exploitation

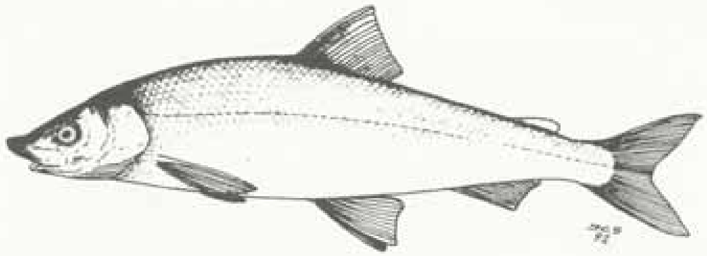
The houting has previously been commercially exploited for its esteemed flesh, being sold either fresh or smoked. The catch in southern *Denmark* used to exceed local demand, and houting was exported to Hamburg and London.

Past and present distribution

In the 19th century the distribution area of the houting included the coasts of *Belgium, The Netherlands, Germany, the United Kingdom, Denmark,* and all the Baltic countries. Its distribution is now dramatically curtailed, however (*Figure 59*), the only population in *Denmark* being associated with the river Vidå system (Ejbye-Ernst et al. 1988). Other populations are reported to exist in the Baltic area.

Threats and protection measures

The houting has been assigned the status of a globally endangered species by IUCN. An important factor in its decline has been the establishment of dams and weirs, the houting being unable to pass even minor obstacles (Ejbye-Ernst et al. 1988). Destruction of its spawning grounds as the result of channelization and stream maintenance as well as the general deterioration in water quality have also contributed to its decline, as have coastal eutrophication and overfishing (Lelek, 1987).



Houting (*Coregonus oxyrinchus* (L.))

Maitland (1991) states that there is urgent need for strict protection of the species in at least two or three rivers. This has been implemented in the river Vidå in southern *Denmark* where access to houting spawning grounds has been reestablished and the spawning grounds have been protected by a changed maintenance practice and reduced sediment transport. In addition, the use of gillnets has been prohibited in the adjacent marine environment. These efforts have been supplemented since 1981 by the stocking of fry. The project has been very successful, and the houting population in the river Vidå appears to have been saved from extinction (Ejbye-Ernst et al. 1988).

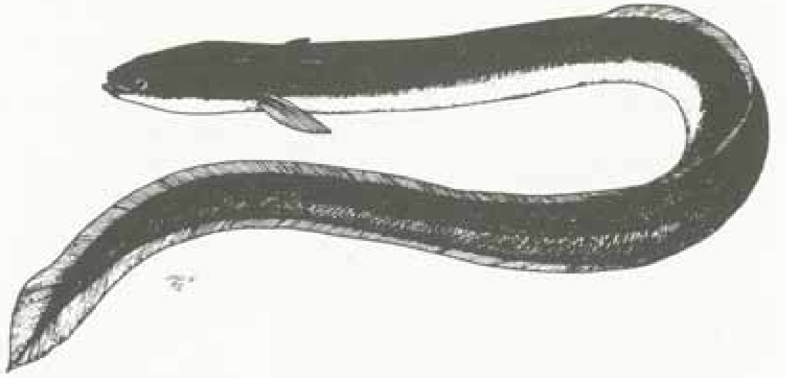
Figure 59: Distribution of the houting in Europe. (Redrawn from Holčík, 1989)

European eel

Anguilla anguilla (L.)

Characteristics and biology

The adult eel is very characteristic and well-known. The colour of its belly changes from yellow (yellow eel) to silvery white (silver eel) as it approaches sexual maturity. Males rarely exceed a length of 0.5 m whereas females may reach 1.5 m and weigh 7 kg.



European eel
(*Anguilla anguilla* (L.)

The eel is migratory and lives in coastal brackish water or fresh water. The larvae differ significantly from the adult and only inhabit the ocean. They metamorphose into glass eel which, except for their lack of pigmentation, look like adult eel. These enter fresh water and stay there for 4-9 years in the case of males and 6-13 years in the case of females. Eels inhabit lakes and streams, but avoid swiftly flowing water. They mainly feed by night on a wide variety of animals. When approaching sexual maturity they virtually stop feeding and start their migration to the Sargasso Sea, where they spawn.

Exploitation

The eel is a valuable fish for consumption, the annual catch being about 15 000 tonnes. In order to increase the catch young eels are caught along the western coast of Europe and released in inland waters. Some of the young eels are used for human consumption, however.

***Figure 60*:**
Distribution of the European eel in Europe.
(Redrawn from Holčík, 1989).

▨ Natural distribution area
☐ Enlarged distribution by stocking

Past and present distribution

The eel enters estuaries of all rivers emptying into the Atlantic, the North Sea, the Baltic and the Mediterranean Sea, although few eels reach the Black Sea (*Figure 60*). Its area of distribution has hardly changed, but its population density has decreased in many rivers. The eel appears to have become extinct in the central part of the Iberian Peninsula (Lelek, 1987).

Threats and protection

The main reason for the decline in eel population density is the significant decrease in the number of young eels that migrate into fresh waters. The cause of this decrease is unknown. Some eel populations have been wiped out by excessive pollution, eg. in the Rhine in the 1960s and 1970s. As dams and other physical obstacles prevent eels from reaching upstream parts of many river systems, the populations in these areas are dependent on stocking.

The eel is not a threatened species and the protective measures taken have mainly been to maintain the eel catch. These measures include establishing passages for their upstream migration (eel passes), catch size limits and large-scale stocking schemes.

Birds and mammals associated with European fresh waters

Approximately 25 per cent of all European birds and 11 per cent of all European mammals are dependent on freshwater wetlands for breeding or feeding; of these a higher proportion of mammals than birds are introduced species whereas the majority of birds but only a single mammal are migratory (*Table 14*). Only one species of each group is truly endemic to Europe and a further two species almost endemic (*Table 15*).

Due to their size and mobility birds and mammals use a wide variety of freshwater habitats, very few species being confined to only one specific environment. Prominent examples of the latter are the beaver, which builds dams across rivers, and the harlequin duck, which breeds along tearing rivers in *Iceland*.

Birds such as the swan and the coot are important for the biological structure of shallow lakes. By grazing on submerged macrophytes they affect sediment-water nutrient

Table 14:
Number of bird and mammal species in Europe (Corbet & Ovenden, 1980; Peterson et al. 1983).

	Birds	Mammals
Total in Europe	504	138
Dependent on fresh water	124	15
- introduced	4	4
- migratory	119	1

Table 15:
Endemic or almost endemic European birds and mammals. (Ellerman & Morrison-Scott, 1951; Corbet & Ovenden, 1980; Peterson et al. 1983).

	Birds	Mammals
Endemic	Aquatic warbler *Acrocephalus paludicola* (Vieillot)	Southwestern water vole *Arvicola sapidus* Miller
Almost endemic	March warbler *Acrocephalus palustris* (Bechstein)	Millers water shrew *Neomys anomalis* Mottaz
	Reed warbler *Acrocephalus scirpaceus* (Hermann)	European mink *Mustela lutreola* (L.)

Table 16:
European birds and mammals included in the red lists of globally threatened species from IUCN, 1988 and ECE, 1991.

	Birds	Mammals
Endangered	Dalmatian pelican *Pelecanus crispus*	Ringed seal *Phoca hispida saimensis*
Vulnerable	Marble teal *Marmaronetta angustirostris* White-headed duck *Oxyura leucocephala*	Long-fingered bat *Myotis capaccinii* European mink *Mustela lutreola* Eurasian otter *Lutra lutra*
Rare	Lesser white-fronted goose *Anser erythropus* White-tailed sea eagle *Haliaeetus albicilla*	
Probably threatened		Pond bat *Myotis dasycneme*
Under consideration	Pygmy cormorant *Phalacrocorax pygmeus* Red-breasted goose *Branta ruficollus* Slender-billed curlev *Numenius tenuirostris* Aquatic warbler *Acrocephalus paludicola*	

exchange and sediment resuspension, as well as the refuges used by zooplankton and fish fry. Furthermore, they can significantly delay macrophyte recolonization and hence recovery in lakes following a reduction in nutrient loading.

Nine bird and five mammal species related to European freshwaters are included on the International Union for Conservation of Nature and National Resources (IUCN) Red List of Globally Threatened Species, and of these only two species are endangered by extinction (*Table 16*). However, many other species are actually endangered or vulnerable in Europe, but are not included on the list because their presence in other continents means that they are not globally threatened.

European freshwater birds and mammals are affected by numerous environmental problems. Deterioration of water quality, channelization, etc. seriously affect birds and mammals. In addition they are faced with a range of other environmental threats that include hunting, human persecution, tourism, and power lines across rivers and lakes. In the case of migratory birds, further threats occur while migrating or at their winter quarters. The management of birds and mammals therefore necessitates more than just water management, and often requires international cooperation.

Birds

Great white pelican and Dalmatian pelican
Pelecanus onocrotalus L. and *Pelecanus crispus* Bruch

Characteristics and biology
Pelicans have a very characteristic appearance with a pouched underbill that is used as a dipnet with which to scoop for fish. Having seen flocks of fishing pelicans on TV nature programmes, most people associate them with tropical America, Africa, and Asia. However, of the seven species of pelicans known, the two largest actually occur regularly in southeastern Europe. These two species, the great white pelican and the dalmatian pelican, both have a wing span of 2.7-3.6 m (Cramp & Simmonds, 1977). The adults are easily distinguished in flight, the underside of the flight feath-


Great white pelican (*Pelecanus onocrotalus* L.)


Dalmatian pelican (*Pelecanus crispus* Bruch)

ers being whitish grey in the dalmatian pelican but black in the great white pelican.

Both species normally breed in colonies on sandy islands or in dense reed beds in lakes, river deltas or coastal lagoons. Although they produce an average of almost two eggs per nest, the hatching success is low and on average less than one fledged chick survives each year (Crivelli et al. 1991a).

Both pelicans feed exclusively on fish, without being selective. However, whereas the great white pelican normally feeds in large groups and may fly up to 100 km from the breeding colony in order to fish, the dalmatian pelican feeds alone or in two's or three's, and does so relatively close to its colony.

Both species are migratory, the great white pelican probably wintering in the *Sudan* or *Ethiopia* (Crivelli et al. 1991b) and the dalmatian pelican wintering along the coasts of the Adriatic and Aegean Seas.

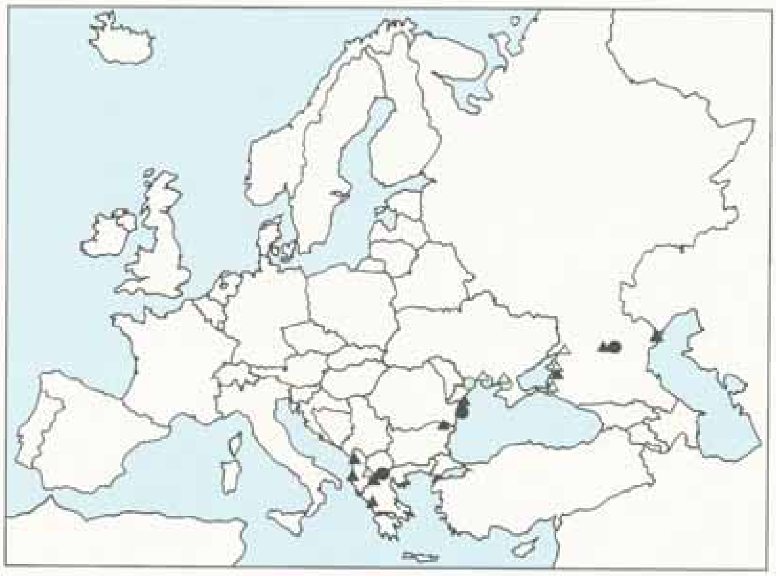


Figure 61:
Distribution of great white pelican (●, ○) and dalmatian pelican (▲,△) in Europe.
● and ▲: presence of a breeding colony (Grimmett & Jones 1989);
○ and △: sites with uncertain status or former breeding colony (Cramp & Simmonds, 1977).

Past and present distribution

The overall geographic distribution of pelicans in Europe has changed little during the last century (*Figure 61*). However, pelicans ceased breeding in inland marshes and lakes along the Danube in northeastern *Serbia-Montenegro*, *Romania*, and *Hungary* in the second half of the 19th century and early in the 20th century. Due to drainage the Crna Reka breeding site in *the Former Yugoslav Republic of Macedonia* has been abandoned since 1955. Finally, the great white pelican has ceased breeding in *Bulgaria* (Cramp & Simmonds, 1977).

For both pelican species the European populations constitute a significant proportion of the estimated world populations (*Tables 17 & 18*). However, there has been a significant decrease in their population size throughout the breeding area. For example, whereas about 6000 pairs of pelicans nested in the Danube delta in 1960-61 (Cramp & Simmonds, 1977), only about half remain.

Threats and protection measures

One of the main reasons for the decline in the population of these two species is intensive reclamation of wetland areas for agricultural purposes. According to Munteanu & Toniuc (1992) the drainage or modification of about one quarter of the Danube delta caused serious problems for the dalmatian pelican, as will future reclamation projects in the Volga delta (Grimmett & Jones, 1989).

Destruction of breeding colonies by fishermen who regard pelicans as an unwanted competitor used to be common, and has also been observed recently (Crivelli et al. 1991a). Other causes of mortality are illegal hunting and collisions with power lines, eg. as has been recorded at Porto-Lago in *Greece*, an important wintering site for the dalmatian pelican (Crivelli et al. 1991a). Serious eutrophication within the feeding area of the dalmatian pelican caused by the establishment of fish-ponds in lakes and coastal lagoons has recently reduced their feeding possibilities. Future plans for increasing fish farming in *Greece* may cause further problems for the pelican populations.

Both pelican species are now considered to be threatened in Europe and the dalmatian pelican is considered by the International Council for Bird Preservation (now Birdlife International) to be globally threatened (King, 1981). All European countries have therefore implemented protection measures including laws prohibiting hunting and other forms of persecution by man, and most breeding sites are now protected (*Tables 17 & 18*).

The future of pelicans in Europe is still dark, although in several cases protection measures have significantly improved the situation. Protection of the breeding sites at Lake Mikrí Préspa in *Greece* has more than doubled the breeding populations (Cramp & Simmonds, 1977) and mortality due to collision with power lines has been reduced either by dismantling them or by erecting scaring flags (Crivelli et al. 1991a). Well designed management plans that include educational measures to reduce illegal killing and the maintenance of important wetlands may therefore provide some hope of ensuring a future for pelicans in Europe.

Table 17:
Estimates of breeding populations of dalmatian pelican in Europe and worldwide.

Country	No. of breeding sites	Total breeding pairs	Most important site	Area protection status
Romania[1]	1	35-115	Danube delta	Nature and Biosphere reserve, Ramsar and World Heritage Site
Bulgaria[1]	1	70-90	Lake Shrebarna	Nature and Biosphere reserve, Ramsar and World Heritage Site
Serbia-Montenegro[1]	1	10-20	Lake Skadarsko	National park
Albania[2,3]	1	10-50	Karavastas	Unprotected
Greece[1]	2	125-210	Lake Mikrí Préspa, Amvrakikós Gulf	Partly Ramsar Site, National Park, EC bird protection Partly Ramsar Site
Russian Federation[2]	3	360+	Lake Manych Gudilo, Sea of Azov, Volga delta	Temporary nature reserve Temporary nature reserve 11% Temporary nature reserve, 10% State reserve
Europe total	9	610-845		
World population[1]	22+	1925-2710		

[1] Crivelli et al. 1991a; [2] Grimmett & Jones, 1989; [3] Gjiknuri & Peja, 1992.

Table 18:
Estimates of breeding populations of great white pelican in Europe and worldwide.

Country	No. of breeding sites	Total breeding pairs	Most important site	Area protection status
Romania[1]	1	3000-3500	Danube delta	Nature and Biosphere reserve, Ramsar and World Heritage Site
Greece[1]	1	40-150	Lake Mikrí Préspa	Partly Ramsar Site, National park, EC bird protection
Russian Federation[2]	1	50	Lake Manych Gudilo	Temporary nature reserve
Europe total	3	3100-3700		
World population[1]	25+	7350-10 500		

[1] Crivelli et al. 1991a; [2] Grimmett & Jones, 1989.

Spoonbill

Platalea leucorodia L.

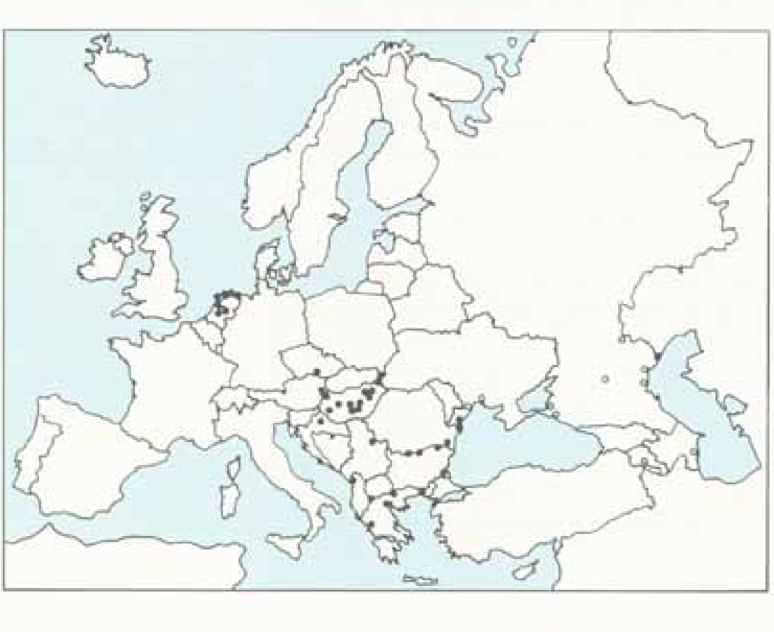
Spoonbill
(*Platalea leucorodia* L.)

Characteristics and biology

The spoonbill is a fairly large white bird named for its spoon-like bill. It can easily be distinguished from white herons by its bill and elongated neck when flying. The spoonbill breeds in dense colonies, sometimes together with the glossy ibis (*Plegadis falcinellus*), and rarely with herons. The colonies are located on the ground in reed beds or in willows. Both parents incubate the 2-4 eggs and feed the chicks.

The spoonbill is carnivorous, feeding on a wide variety of insects and other invertebrates, tadpoles, frogs, and fish in shallow freshwater and brackish lakes and in wet marshes (Cramp & Simmonds, 1977). It winters along the west coast of tropical Africa, in southern *Spain*, *Tunisia*, *Libya*, and *Egypt* (Cramp & Simmonds, 1977).

Figure 62:
Distribution of spoonbill in Europe.
• : presence of a breeding colony (Grimmett & Jones 1989);
○ : sites with uncertain status or former breeding colony (Cramp & Simmonds, 1977).



Past and present distribution

The distribution of the spoonbill in Europe is fragmented (*Figure 62* and *Table 19*). The main breeding area is in southeastern Europe but isolated populations occur in *The Netherlands* and in southern *Spain*. There has been no major change in its overall distribution this century, although temporary settlement has occurred in parts of *Denmark*, *Germany*, *France*, and *Portugal*. The breeding populations have fluctuated widely, however. Thus the number of breeding pairs in *The Netherlands* has increased from about 300 in 1900 to about 600 in 1992, the minimum being about 150 pairs in 1968-69 (Cramp & Simmonds, 1977; SOVON, 1987; Koffijberg & Voslamber, pers. comm.). Breeding in *Spain* was irregular for many years but then increased from 300-500 pairs in the early 1970s to about 650 pairs today. The number of breeding pairs has decreased in *Austria*, *the former Yugoslavia*, *the Ukraine*, *Romania*, and *Greece* and the spoonbill has ceased breeding in *the Former Yugoslav Republic of Macedonia*. The general picture is therefore of an increase in spoonbill number in *The Netherlands* and *Spain*, and a decrease in southeastern Europe with the exception of *Hungary*.

Threats and protection measures

The difference in the breeding success of the different populations may be attributable to differences in the conditions pertaining in their wintering areas and/or in the breeding areas. Thus while the Dutch and Spanish birds winter in the undisturbed western tropical Africa (Ens et al. 1990), the southeastern European populations winter along the Nile and in *Tunisia*, and may therefore be affected by the agricultural development in these areas (Finlayson et al. 1992). Similarly that the breeding areas in *The Netherlands*, *Spain*, and *Hungary* are protected and to some extent managed (Voslamber, 1992; Szekely, pers. comm.), whereas agricultural reclamation of wetlands is pronounced along the Danube, in the Danube delta and in *the Former Yugoslav Republic of Macedonia*, suggests that differences in breeding area protection may partially explain the differences in population development.

Table 19: Estimates of European breeding populations of spoonbill.

Country	No. of breeding sites	Total breeding pairs	Most important breeding sites (no. of pairs)
Netherlands[1]	10	571	Oostvardersplassen (235)
Spain[2]	2	650	Marimas del Guadalquivir (350) Rio del Huelva (300)
Austria[2]	1	50	Neusiedler See (50)
Former Czechoslovakia[2]	3	4-6	Stredni nádrz (2-4)
Hungary[2]	10	655-725	Hortobagy (400-450)
Romania[2]	2+	60+	Danube delta (60)
Bulgaria[2]	4	45-115	Belene Island (20-60)
Croatia[2]	1	150-170	Krapje Dol (150-170)
Bosnia-Herzegovina[2]	+	1	Bardaca
Serbia-Montenegro[2]	2	65	Obedska Bara (40)
Greece[2]	5	50+	Lake Kerkinitis (30)
Ukraine[2]	1	60	Danube delta (60)
Russian Federation[2]	1	300-1200	Volga delta (300-1200)
Europe total	43+	2660-3725	

[1] Koffijberg & Voslamber, pers. comm.; [2] Grimmett & Jones, 1989.

Spoonbills are protected from hunting by legislation in all European countries and most of their breeding colonies are at least partly protected, including all five areas in which there are more than 200 breeding pairs. The future of the Dutch and Spanish populations looks bright, in sharp contrast to that of the southeastern European populations. However, the success of protection and management measures in *Hungary* clearly indicates that it is possible to reverse the trend, a precondition being though that the degradation and loss of wetlands in the spoonbill's Mediterranean breeding and wintering areas be stopped.

Purple heron

Ardea purpurea L.

Purple heron (*Ardea purpurea* L.)

Characteristics and biology

The purple heron has the typical appearance of a heron, but is slightly smaller than the more common grey heron (*Ardea cinerea*) from which it can be distinguished by its reddish neck and blackish belly. It breeds in dense colonies, either alone or together with other heron species. The colonies are located near shallow freshwater or brackish lakes, either on the ground in reed beds or in bushes or small trees (Cramp & Simmonds, 1977). The nests are made of reed or twigs and usually contain 4-5 eggs. The chicks are fed by both parents.

The purple heron feeds primarily on fish, but also on insects and occasionally reptiles and rodents (Cramp & Simmonds, 1977). Its feeding areas are mainly shallow freshwater and brackish water bodies while in the Po and the Ebro deltas, rice fields have become an important feeding habitat (Hafner & Fasola, 1992). It is migratory, the main wintering quarters being in the Sahel region of Africa, along the Niger and Senegal rivers.

Past and present distribution

The purple heron is mainly distributed through southern Europe (*Figure 63*). Since the 1940s it has established several temporary settlements with fluctuating numbers of breeding pairs along the border of its present area of distribution. The European breeding population is estimated to be 10-12 000 pairs, large breeding populations being found in *the Russian Federation, France, Romania,* and *Spain* (*Table 20*).

Figure 63: Distribution of purple heron breeding colonies in Europe. (France: Yeatman, 1976; The Netherlands: SOVON, 1987; Remaining areas: Grimmett & Jones, 1989).

Purple heron populations have fluctuated widely in the various European countries. For example in *The Netherlands*, the breeding population varied between 400-1000 pairs during the period 1961-79, the maximum being in 1976-77 (Held, 1981). The population then declined to 300 pairs and was between 270-290 pairs in 1985-89 (SOVON, 1987; Kooij, 1991). Population size in *The Netherlands* has been found to be significantly related to annual precipitation in the main winter quarters since droughts reduce survival of immature and adult birds, and hence the breeding population (Held, 1981; Cavé, 1983). Breeding populations have also fluctuated widely in other countries and there appears to be an overall decline in population size. In *Switzerland*, for example, the last breeding pairs left in the 1970s.

Threats and protection measures

The main reason for the fluctuating Dutch population of purple herons is mortality associated with drought in its wintering quarters in Africa, whereas the population is not being limited by lack of feeding or breeding areas in *The Netherlands* (Held, 1981). Little is known about what regulates the purple heron populations in other European countries, but intensified use of wetlands in the Mediterranean area is probably a serious threat, as it is for other waterfowl (Finlayson et al. 1992). The purple heron is protected from hunting by legislation in all European countries, and many of the more important breeding colonies are located in protected wetland areas (Grimmett & Jones, 1989).

Although rice fields provide excellent feeding habitats for the purple heron, intensified water-level management and the use of pesticides may be a threat (Hafner & Fasola, 1992; Ruiz et al. 1992). Research is therefore needed

Table 20: Estimates of European breeding populations of purple heron.

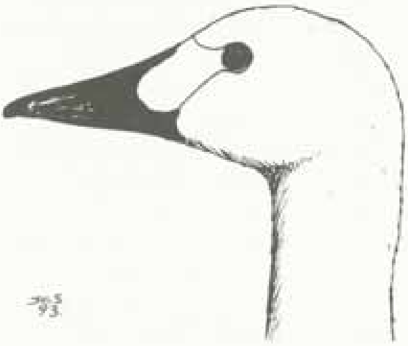
Country	No. of breeding sites	Total breeding pairs	Most important breeding sites (no. of pairs)
Netherlands[1]	16	285-640	Nieuwkoop (122)
Belgium[2]	1	2	Viverkomplex van Midden Limburg
France[2,3]	126+[3]	2740[3]	Camargue (400)
Spain[2]	11+	1078-1378+	Marimas del Guadalquivir (500+)
Portugal[2]	10+	45++	Tajo estuary
Italy[2]	29	714-767	Po delta (150)
Germany[2]	6	21-29	Wagbachniederung (10)
Austria[2]	2	105	Neusiedler See (100)
Former Czechoslovakia[2]	9+	25-75	Danube flood plains (5-30)
Hungary[2]	13	297-327	Hortobagy (125)
Romania[2]	1+	1250+	Danube delta (1250)
Bulgaria[2]	5+	6-76++	
Croatia[4]	3	44	Jelas (30)
Serbia-Montenegro[2]	7+	310-610+	Ludasko jezero (100-300)
Albania[2]			Ligen i Butrintit
Greece[2]		184-201+	Néstos delta (40)
Ukraine[2]	1+	400+	Danube delta (400)
Russian Federation[2]	1+	2500+	Volga delta (2500)
Europe total	240+	10 000-12 000	

[1] Kooij, 1991; [2] Grimmett & Jones, 1989; [3] Yeatman, 1976; [4] Mikuska, 1992.

to develop a management strategy that will enable high rice production, while at the same time ensuring high quality feeding areas for the purple heron. Such a strategy would ensure that large populations of the purple heron survive in Europe in the future.

Bewick's swan

Cygnus columbianus bewickii (Ord)



Bewick's swan
(*Cygnus columbianus bewickii* (Ord))

Characteristics and biology

The Bewick's swan is the smallest of the three swan species found in Europe, being only half the size of the common mute and whooper swans. It is purely white except for the black legs and yellow and black bill.

The Bewick's swan breeds near lakes and rivers in the northeastern Russian tundra, and is territorial when breeding. It nests on the ground and usually lays 3-5 eggs. These are incubated by the female although both parents take care of the cygnets when they hatch (Cramp & Simmonds, 1977). After breeding the swans migrate via the Baltic to the wintering areas in western Europe. The species is gregarious when moulting, migrating and wintering.

The Bewick's swan is vegetarian, preferring submerged macrophytes and especially pond weeds (*Potamogeton* spp.). Changes in land usage have forced the Bewick's swan to change its diet during wintering. Earlier in this century swans wintering in *The Netherlands* fed on pond weeds in rivers and eelgrass in shallow coastal waters; however, by the mid 1960s their main feeding habitat had changed to arable land (Poorter, 1991). Although submerged macrophytes are still preferred, they appear to be depleted in the autumn (Beekman et al. 1991; Dirksen et al. 1991) and the swan's winter diet now consists mainly of left-overs in sugar beet, potato, wheat, grass, and rape seed fields (Dirksen et al. 1991; Poorter, 1991; Zijlstra & Laubek, pers. comm.) Similarly, Bewick's swans wintering in *the United Kingdom* also changed their feeding habitat from the flooded or wet pastures preferred in the 1960s to arable land in the 1970s (Cramp & Simmonds, 1977).

Past and present distribution

The distribution of Bewick's swan has not changed in this century. The species breeds west and east of the Pechora river delta on the northeastern Russian tundra and on Vaigach Island (Mineyev, 1991), and winters in *Denmark*, *Germany*, *The Netherlands*, *the United Kingdom*, *Ireland*, and occasionally *Belgium* and *France* (*Figure 64*). The wintering population in Europe is estimated to have increased from 6-7000 birds in the 1970s (Cramp & Simmonds, 1977), to 15-17 000 birds in 1982-87 (Dirksen & Beekman, 1991). At the same time it has been estimated that there are 30-36 000 birds in the breeding area (Mineyev, 1991). The reason for the discrepancy between these two estimates is unclear, only a few hundred of the breeding population being known to winter elsewhere (Cramp & Simmonds, 1977; Ardamatskaya & Korzyukov, 1991).

Threats and protection measures

The Bewick's swan is protected against hunting in all European countries. Nevertheless, about 40 per cent of the Bewick's swans examined in *the United Kingdom* had shotgun pellets in their bodies (Rees et al. 1990), thus suggesting that illegal hunting is a real threat. It is not threatened in its breeding area, how-

Figure 64:
Distribution of Bewick's Swans in Europe.

▨ Breeding area (Mineyev, 1991)
■ Wintering area (Cramp & Simmonds, 1977)

ever, and the conflict between crop owners and swans in the wintering quarters could be solved. There is therefore a good chance that the population of Bewick's swans will be maintained.

Osprey

Pandion haliaetus haliaetus

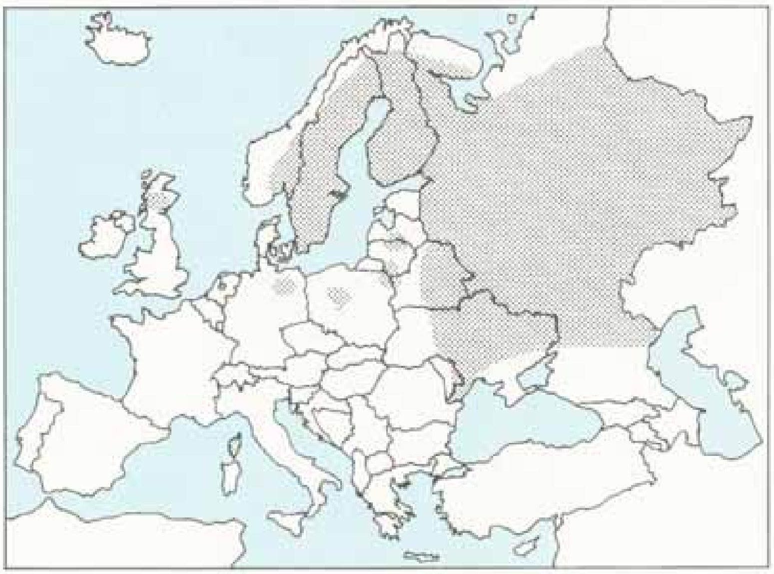
Osprey *(Pandion haliaetus haliaetus)*

Characteristics and biology

The osprey is a medium sized eagle-like bird of prey that is easily recognizable by the contrast between its blackish upper side and its snowy white underside with a black spot on the carpus.

Most ospreys nest in trees in undisturbed inland or coastal forests (Gensbøl, 1985), but the Mediterranean birds nest on rocky promontories (Poole, 1989). The osprey becomes fertile at an age of 3-5 years and the pairs stay together using the same nest year after year. They lay an average of three eggs with the number tending to increase at higher latitudes. In viable populations 1.5-2 fledglings leave each nest (Odsjo & Sondell, 1976; Nilsson, 1981; Saurola, 1986; Poole, 1982, 1989).

Figure 65:
Distribution of ospreys in Europe.
(Poole, 1989).



Osprey feed almost entirely on live fish that they catch from the surface of inland or coastal waters, their feet being used to hold the prey. They are opportunistic and feed on the most abundant fish species.

Most osprey migrate, primarily wintering along the large African river systems south of latitude 20° N. However, a few Mediterranean birds remain along the Mediterranean coast all year round.

Past and present distribution

The osprey is a truly cosmopolitan species, inhabiting five continents. It bred all over Europe in the 18th century but became extinct in a number of countries, including *Ireland* (early 18th century), *the former Czechoslovakia* (mid 18th century), *Hungary* (late 18th century), *the United Kingdom* (1910), *Switzerland* (1911), *Denmark* (1916), *Austria* (1930s), *France* (1945), *the former Yugoslavia* (1950s), *Romania* and *Germany* (1960s), and *Greece* (1966) (von Blotzheim et al. 1971; Bijleveld, 1974).

The osprey has now returned to some of the countries it abandoned and is now breeding in northern and eastern Europe, in *Scotland*, and the western Mediterranean (*Figure 65*). The largest populations are found in *Sweden* and *Finland* where there are about 3000 birds, or two thirds of the European total. Both populations appear to be successful (Osterlof, 1973; Odsjo & Sondell, 1976; Saurola, 1986). The Scottish population recolonized in 1958 and has increased to more than 50 pairs (Poole, 1989; Stroud & Glue, 1991). The Mediterranean populations are as yet still confined to a few islands and remote stretches of the coast.

Threats and protection measures

The osprey has been hunted in Europe for centuries and although presently illegal, egg stealing and hunting still threaten weak populations (Dennis, 1983). Timber harvesting and hence the destruction of suitable nesting sites has also occurred widely throughout Europe. The osprey is now legally protected from hunting in all European countries. Furthermore, artificial nesting sites have been established in many countries, eg. in *Germany* where more than half of the osprey population use artificial sites (Meyburg & Meyburg, 1987).

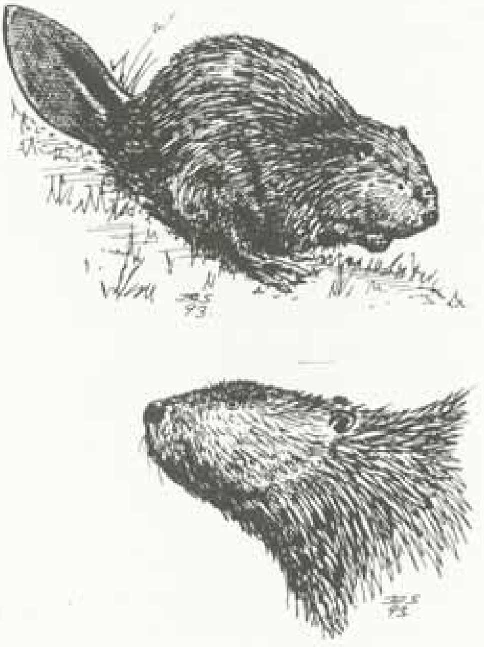
While mercury and dieldrin pollution are known to have had a local impact on breeding, organochlorines and PCBs do not seem to have affected European osprey populations, and there is no evidence of accumulation of toxins in their winter quarters (Poole, 1989). Acidification of Scandinavian inland waters has only slightly affected osprey reproduction (Clum, 1986; Eriksson, 1986).

Although the Mediterranean and Baltic populations are still decreasing, the overall picture is of a variable but slowly increasing European osprey population, the increase mainly being attributable to increasingly effective protection and management of both the populations and their habitats.

Mammals

European beaver and Canadian beaver

Castor fiber (L.) and
Castor canadensis Kuhl



Beaver
(*Castor* sp.)

Characteristics and biology

The beaver is one of the largest rodents, its adult weight being about 20 kg and its body length 1 m. The Canadian beaver is somewhat larger than the European beaver. Both species are well adapted to a semi-aquatic life. Their fur is very dense, their back feet have skin between the toes, their front feet have five fingers with large nails for handling and digging, and their hairless flat tail is used for steering and paddling. When disturbed or exited they communicate by banging their tails on the water surface.

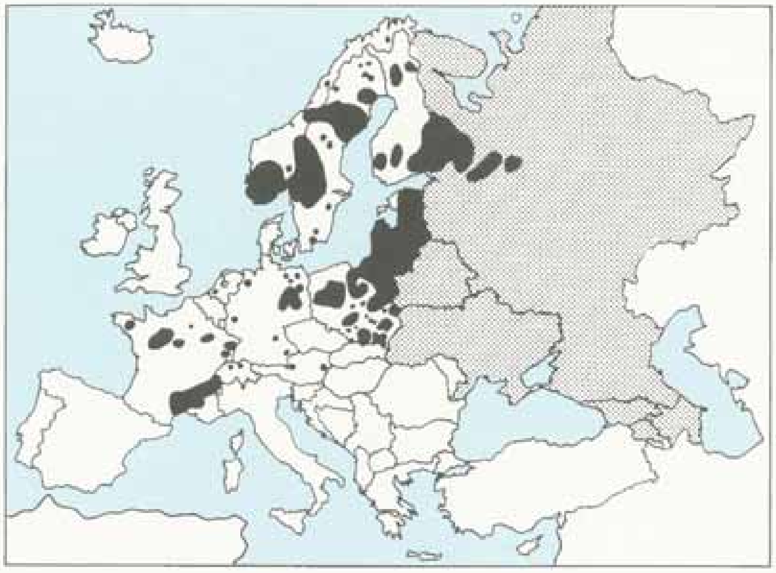


Figure 66: Distribution of the European and Canadian beaver in Europe. (Updated from Lavsund, 1987).

■ Known population
▨ Present, but distribution unknown

Both species inhabit rivers and lakes in areas with deciduous forest and the signs of their presence are numerous. In rivers with fluctuating water levels they build dams as much as 20 m long and 3 m high, often with the result that surrounding trees are killed by flooding. They fell trees with a stem diameter up to 40 cm, especially those close to the water, and build highly developed beaver lodges of branches and twigs, tightened by mud and stones. The lodges often have several rooms used for different purposes such as sleeping, eating etc. The entrance tunnel is submerged and the lodge is therefore safe from predators. Air channels at the top ensure a good inner climate.

Both the European and the Canadian beaver are territorial and live in small family groups consisting of parents and offspring from the last two years. The European beaver normally has 2-4 offspring, which are weaned after about two months (Zharkov & Solokov, 1967; Valeur, 1990), whereas the Canadian beaver normally has 4-5 offspring. This may explain the higher rate of increase of the latter in those areas of *Finland* where the two species were introduced almost simultaneously (Lahti & Helminen, 1974). At an age of 2-3 years the offspring leave their home range and establish their own family groups.

Both species feed mainly on fresh bark, twigs, leaves, buds and sap from hardwood trees such as aspen, birch, alder, willow, oak,

Table 21:
Estimates of European beaver (*Castor fiber)* and Canadian beaver (*Castor canadensis*) populations in European countries.

Country	Species	Numbers	Reintroduced
Norway[1,2]	*C. fiber*	40 000	-
Sweden[3]	*C. fiber*	100 000	1922
Finland[4]	Mixed	6000	1937
	C. fiber	600	1937
Netherlands[5]	*C. fiber*	35	1988
Germany[3]	*C. fiber*	4000	
former Eastern[6]		2500-3000	Aboriginal
former Western[7]		800-1200	1972-74
France[3]	Mixed	2000	?
Switzerland[3]	?	100-150	1956-77
Austria[8]	*C. fiber*	150	1976
Poland[9]	Mixed	5000-10 000?	1940s
Estonia[10]	*C. fiber*	4000	1957
Latvia[11]	Mixed?	50 000	1927-52
Lithuania[12,13]	Mixed?	14 000	1947-59
Ukraine/Russia/Belarus	Mixed	200 000?	1960-92?

[1]Kortner & Bendixen, in press; [2]Myrberget, 1967; [3]Hartman, pers. comm.; [4]Lahti, in press; [5]Nolet, in press; [6]Heidecke, 1977; [7]Reichholf, 1977; [8]Bratter & Sieber, in press; [9]Zurowski, 1988; [10]Laanetu, in press; [11]Balodis, in press; [12]Mickus, in press; [13]Palionene, 1965.

and rowan (Myrberget, 1967; Lahti & Helminen, 1974; Reichholf, 1977; Stocker, 1984). In the autumn they store branches outside the entrance tunnel of their lodge to be used as food in the winter, while in spring and early summer macrophytes form an important part of their diet.

Past and present distribution
The European beaver used to be widespread in Europe, but disappeared from *the United Kingdom* as early as the 11th century and from most central European countries during the 18th century. At the beginning of the present century a total of only a few hundred animals remained in Europe, these being restricted to *Norway, Germany, France,* and *the former Soviet Union* (Valeur, 1990).

The beaver population in Europe has now increased again to at least half a million (*Table 21* and *Figure 66*). The European beaver is the sole species in *Norway* and *Sweden* while the Canadian beaver is dominant in most other countries. The European beaver was reintroduced to *Sweden* from *Norway* in 1922. The Swedish population has expanded from 80 animals in 1922-39 to about 100 000 animals in 1992, the population having doubled every 6-7 years since 1969. This expansion is attributable to the large areas of suitable habitats and the restricted hunting.

Although recent population estimates are lacking for some countries, the beaver population is known to be increasing in *Norway, Finland, Austria, Germany, Latvia*, and *Lithuania*.

Threats and protection measures
The decimation of European beaver populations prior to the present century can mainly be attributed to the hunting of beaver for its fur and beaver oil (*Casteorum*), as well as to deforestation and subsequent afforestation with conifers. Since its reintroduction, beaver populations have been protected and hunting has been restricted. As a result, the recent population size in many countries is the highest ever recorded.

In some central European countries a lack of suitable habitats has kept the beaver populations at a low level. However, as the beaver is generally well protected, the populations in Europe can be expected to increase further.

Eurasian otter
Lutra lutra L.

Eurasian otter (*Lutra lutra* L.)

Characteristics and biology
The Eurasian otter is one of 13 otter species found worldwide. Like the other species it is well-adapted to an amphibious life. Its fur is comprised of a dense insulating underfur, which remains dry when the otter is swimming, and an overlying layer of waterproof guard hairs. Furthermore, it has a long sinuous body with a flattened head and small ears which, together with its short legs and webbed five-toed paws, make it an excellent swimmer.

The Eurasian otter inhabits a wide variety of freshwater, brackish, and marine habitats. In Europe it is found in streams, lakes, marshes, and in coastal areas, where rainfall provides the freshwater pools required for drinking and bathing. It is rarely found in high mountain streams. It spends considerable time on land and requires secure water-side cover for nesting and rearing cubs. Most otter populations are nocturnal, although coastal populations are active during the daytime.

The Eurasian otter is territorial, its territory being delineated with faeces (spraints) frequently deposited at conspicuous sites. Field surveys of spraints and footprints enable otter density to be estimated despite it being elusive and usually nocturnal. One survey in a Scottish river found that the male home range extended over 39 km of river, twice that of the females (Green et al. 1984). Coastal otters have much smaller home ranges.

Eurasian otters normally live alone, except during the mating season. They have one to three offspring which may stay with the female for up to a year before they are weaned.

Foraging takes place mainly in the water, the diet consisting predominantly of fish; being opportunistic, it eats whatever species is easiest to catch. Amphibians and crustaceans sometimes form an important part of its diet, however (Jenkins & Harber, 1980; Weber, 1990; Fairly, 1984; Delibes & Adrian, 1987).

Past and present distribution

The Eurasian otter is widely distributed, being found from Ireland in the west to *Japan* in the east, and from arctic regions in the north to North Africa and *Sri Lanka* in the south. A century ago it was found all over Europe, but its distribution has since changed significantly and is now highly fragmented (*Figure 67*).

The Eurasian otter is still widespread along the Atlantic coast of *Portugal*, western *Spain* and *France*, *Ireland*, and *Scotland*, but is absent or rare in large parts of central Europe and *Italy*. It is also widespread in large areas from *Finland* in the north to the Balkans in the south, although its distribution is tending to become fragmented. While very little information is available from *the former Soviet Union*, the Eurasian otter is known to be widespread in Belarus, Karelia, and Murmansk, albeit that the population density has declined in recent years (Sidorovich & Lauzhel, 1992).

Threats and protection measures

The main reason for the decline of the Eurasian otter in most European countries is the destruction of suitable habitats as a result of the channelization of rivers, drainage of wetlands and deforestation of riparian areas. Other important factors have been hunting and trapping, urbanization and increased disturbance in its habitats. The otter is now protected from hunting and trapping in all western European countries and in some of the eastern European countries. The measures taken in countries with threatened or endangered populations include habitat restoration, the establishment of corridors to promote exchange between sub-populations, and the prevention of accidental death in traffic or fishing nets (ie. by using otter grids). Nevertheless, the future of the Eurasian otter in Europe lies in effectively safeguarding the species in those countries in which it currently thrives and is widespread, eg. *Finland*, *Greece*, *Ireland*, *Portugal*, and *Spain*. The international significance of the Eurasian otter populations in these areas should be recognized, and resources allocated to protect them.

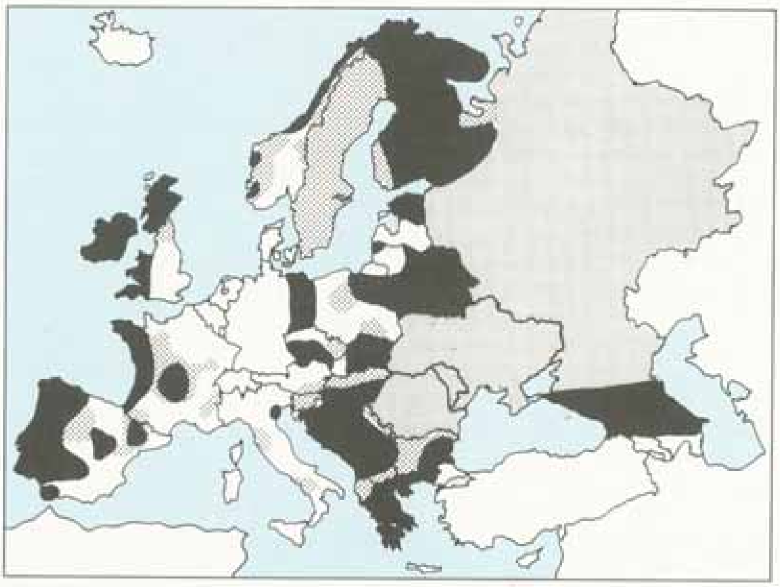


Figure 67: Distribution of the Eurasian otter in Europe.
(Foster et al. 1990).

■ Widespread
▨ Rare
□ Unknown

Photo: Martin Søndergård

5 Current situation and the way forward

This report is one of the first to attempt an overall assessment of the environmental state of European rivers and lakes. Various sources were used in its compilation, including the scientific literature, questionnaires submitted to the national focal point of each country, and national or local reports on the environmental state of inland surface waters. The wide variety of organizational structures pertaining at the national and local level in European countries means that monitoring programmes are extremely diverse. As a consequence the information collated in this report is not always directly comparable, for instance because of differences in the design of monitoring networks, the variables selected, and the analytical methods used.

Monitoring of basic water quality variables such as the concentration of organic matter and nutrients is widespread in Europe, considerable environmental information on rivers and lakes currently being collected and reported by various local and national authorities, as well as by international networks such as the EU river network (which pursuant to Council Decision 77/795/EEC reports on important large rivers) and the OECD and UNEP/GEMS networks (which primarily focus on large rivers and lakes).

Countries situated in the catchments of transboundary rivers and lakes or sharing marine areas usually establish some form of environmental cooperation, as is for example the case with the *Danube*, the *Rhine*, the Baltic Sea, the North Sea, the Mediterranean Sea and the Black Sea. In several cases, such cooperation has resulted in the establishment of monitoring programmes covering a specific river or lake, or all major rivers discharging into the sea. A few international environmental information networks focusing on specific environmental issues have also been set up, eg. the UN/ECE cooperation on acidification of inland surface waters. Although these networks collect valuable information on specific rivers and lakes or on specific issues, the data gathered are often unsuitable for making a general assessment of the environmental state of inland waters. For example, although acidification surveys generally include measurement of nitrate concentration, the lakes and streams included are often situated in mountain ranges or in areas with soil and bedrock poor in limestone, and hence are not necessarily representative of all the lakes and rivers in the country.

Differences in monitoring strategies

Examples of how monitoring strategies differ include the following:

- Monitoring network design
- Differences in water quality variables and methods of analysis
- Sampling frequency
- Descriptive statistical variables
- Sparsity of national reports on the environmental state of rivers and lakes

Monitoring network design

In many countries the environmental state of rivers or lakes is assessed by means of national monitoring programmes or surveys based on a limited number of representative river and lake monitoring stations selected so as to provide an overview at the national level. The design of such networks falls into two main categories; in countries such as *Portugal*, *Spain*, *Germany*, and *Austria*, the monitoring stations are concentrated in large river systems (eg. the *Douro*, the *Tajo*, the *Rhine*, and the *Danube*), while in countries such as *Denmark*, *Sweden*, *Finland*, and *England*, the stations are more evenly distributed to cover both large and small rivers.

Differences in water quality variables and methods of analysis

Although basic water quality variables such as organic matter, oxygen, phosphorus, and nitrogen are often included in European river monitoring programmes, differences in the array of variables measured and the methodologies used render the information provided by the various monitoring programmes difficult to compare. The following examples illustrate the problem:

a) The organic matter content of river water is sometimes measured as the Biochemical Oxygen Demand (BOD), but sometimes as the Chemical Oxygen Demand (COD), which are not directly comparable. Moreover, there may also be differences within each method. For example, BOD can be measured for two, three, five, or seven-day periods, and with or without inhibition of nitrification, at least eight different variables describing the concentration of organic matter (BOD).
b) Phosphorus is measured as dissolved orthophosphate in some programmes, but as total phosphorus in others.
c) Some monitoring programmes include all general nitrogen variables (eg. total nitrogen, dissolved nitrate+nitrite, and ammonium), while other programmes include only nitrate, and occasionally ammonium.
d) In some countries analysis for specific pollutants such as heavy metals and organic micropollutants is not undertaken, either because they are not considered a threat, or because of analytical difficulties.
e) Biological assesment of river quality is undertaken using numerous different methods including a number of different classification schemes.

Sampling frequency

The frequency of sampling in the various monitoring programmes varies widely, ranging from continuous or daily to once annually. Moreover, while some monitoring programmes use the same sampling frequency at all river stations, others sample more frequently in large rivers and less frequently in small rivers. Comparison of data is therefore not always possible. Another problem is that if the number of annual samples is low, it may not be statistically sufficient to reveal water quality trends; the number needed depends on the water quality variable in question, the number of years over which it is being examined, and the magnitude of the change.

Descriptive statistical variables

The results of the different monitoring programmes are reported using a wide variety of descriptive statistical variables, eg. geometric or arithmetic means, standard deviation, standard error of mean, median, quartiles, minima and maxima. The value of these variables depends on the number of samples. For example, the higher the number of samples, the greater will be the maximum and the closer to the true mean will be the mean.

Sparsity of national reports on the environmental state of rivers and lakes

In many countries river and lake monitoring is performed by local authorities (eg. municipalities, counties, water boards) and the information obtained is not always collated at the national level. In *Germany*, for instance, the rivers and lakes are monitored separately by 16 Länder, while in *France* the country is divided into six large river catchments with the local waterboards having the responsibility for both monitoring and reporting. Since the environmental state of European rivers and lakes is assessed by more than 500 local and regional authorities, collection, analysis, and comparison of the information produced is an enormous task.

Reliable high quality information about the environmental quality of inland surface waters is essential for water management and the implementation of optimal measures to improve environmental quality. Greater knowledge of water quality at the regional, national, and European levels is needed if the management of inland surface waters at the European level is to be improved.

The present report includes only a small part of the considerable quantities of environmental information currently produced, the primary focus being on frequently measured water quality variables. Moreover, the findings are affected by the constraints described above. Assessment of the environmental state of rivers and lakes would be significantly improved if more information could be included and measures were implemented to ensure consistancy and comparability of the information provided. The following section discusses how a European river and lake information system may be established.

European river and lake information system

The primary objective of inland surface water monitoring is to enable assessment of the environmental state of rivers and lakes, to estimate riverine loading of receiving waters (eg. lakes, coastal areas, seas) and to detect trends in specific rivers and lakes, as well as at the regional and national level. The results of the monitoring activities should be used to implement measures to improve the environmental state of the waterbodies. The impact of such measures should be followed by ongoing monitoring. Informing the public of the findings should be an important part of the monitoring activities.

The information obtained from national and regional monitoring programmes should be collated in a Pan-European State of the Environment Report with the aim of 1) assessing the general environmental state of rivers and lakes, 2) identifying areas with severe environmental problems, 3) providing a basis with which to identify and assess environmental threats at the regional and European levels, 4) providing information necessary to ensure that society develops in an environmentally sustainable way, and 5) enabling action to be taken to improve the conditions of rivers and lakes. As such an environmental status report would be based on information from a large number of rivers or lakes, it would be a valuable tool with which to identify overall environmental trends.

An important question is how to ensure that locally gathered information can be used to describe the general environmental state of European rivers and lakes? It would clearly be a mistake to establish both local, regional, national, and Pan-European monitoring networks. The national and Pan-European environmental status reports should be based on the valuable information collated, analyzed, and reported by the local monitoring networks. However, this would require harmonization and standardization of local and regional monitoring programmes, local and regional reporting, and national, European, and international data collection. Consistency and comparability of the information processed by the information collection system would have to be ensured by guidelines and technical reports on monitoring and sampling frequency, as well as on the analysis and reporting of environmental variables, etc.

A successful European river and lake information system would have to include the following elements:

- A representative monitoring network
- A harmonized sampling and analysis programme
- National and regional reporting of the environmental state of rivers and lakes

A representative monitoring network

The monitoring network should be able to provide information on a large-scale spatial (ie. Pan-European) environmental problems as well as to detect trends in geographical regions or groups of water bodies, eg. environmental trends in softwater lakes. The monitoring network should to a large extent be based on existing regional or national monitoring networks supplemented with additional sites in areas with sparse coverage. A number of representative monitoring sites should be selected in each country or large geographical region. Since water quality is a function of natural events and human activities, sites in each country in areas relatively unaffected by human activities should represent the baseline condition and account for natural variation. Sites representing the various categories of land usage and sites in densely populated areas and areas with intensive agriculture or high industrial activity should be selected to represent various environmental stress factors.

A harmonized sampling and analysis programme

To ensure comparable data and information, harmonization and standardization of sampling and analysis programmes should be implemented. In many countries existing monitoring programmes would have to be adjusted in order to meet the requirements for harmonization and standardization.

Many countries do not monitor specific pollutants such as heavy metals and organic micropollutants, for instance because they are not considered to be a threat to their inland surface waters. To expand all programmes to cover every conceivable environmental threat would be impossible. However, in certain cases it may be of great importance to establish surveys focusing on specific environmental issues, eg. acidification of inland surface waters or deterioration of the environmental state of currently unpolluted water bodies. Such surveys could be launched as supplements to general monitoring programmes.

National and regional reporting of the environmental state of rivers and lakes

Each country should commit itself to assess the state of its rivers and lakes at least once every three to five years. The resulting reports should focus on the major environmental problem of each country or large regions of the country. National reporting should be supplemented by the standardized input of information to a Pan-European State of the Environment Report, this being achieved by means of questionnaires and data exchange (generally of aggregated information such as frequency distribution, annual means for chemical water quality variables, etc.). To ensure that the information is comparable, guidelines describing methods of data analysis, reporting, and information supply should be elaborated.

The development of such a European river and lake information system will require the close international cooperation and commitment of the participating countries. The information system should be based on the valuable information collated, analyzed and reported by national and large regional monitoring programmes. The first step should be to elaborate an overview of the existing data sources on the environmental state of European inland surface waters. The overview could be based on national descriptions of existing data sources (eg. monitoring activities, specialized surveys, etc.), together with Pan-European collection and analysis of the national descriptions. On the basis of this overview, a European river and lake information system could be elaborated, including criteria for incorporating national monitoring sites into the international network, proposals for harmonization and standardization of monitoring activities, and ideas for information processing from the national/large regional level to the Pan-European level. The system should be organized on the basis of close international cooperation and commitment by European countries to participate and report on their monitoring activities. The development and coordination of a European river and lake information system is an obvious task for the European Environment Agency.

Appendix

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Glossary

Aerobe: with oxygen.

Anaerobe: without oxygen.

Anthropogenic: produced or caused by man.

Benthos: animals and plants living in and on the bottom sediments of lakes and rivers.

Biochemical Oxygen Demand (BOD): the rate of oxygen consumption by aerobic microorganisms during the decomposition (=respiration) of organic matter.

Biota: total animal and plant species occurring in a specified area.

BOD: see Biochemical Oxygen Demand.

Carcinogen: any substance capable of causing cancer in humans or animals.

Catchment: the area from which water drains into a river or lake.

Chemical Oxygen Demand (COD): chemical oxygen uptake by organic and inorganic compounds in water.

Chlorophyll: photosynthetic pigment in algae and higher plants.

COD: see Chemical Oxygen Demand.

Decomposition: the breaking down of dead plant and animal matter through biological and non-biological processes, thereby recycling the organic and inorganic compounds to the environment.

Ecology: the study of interrelationships between organisms and their environment and each other.

Ecosystem: a relatively self-contained ecological system defined by the types of organisms found in it and their interactions.

Emergent plant: an aquatic plant with erect stems which grow out of the water.

Epilimnion: the upper, warmer layer of a lake during thermal stratification. Above thermocline and the hypolimnion.

Erosion: breakdown and movement of land surface, often intensified by human disturbances.

Eutrophication: excessive enrichment of waters with nutrients, and the associated adverse biological effects.

Flood plain: land adjacent to lakes or rivers which is covered as water levels rise and overflow the normal water channels.

Flow regime: the flow of a river throughout the year.

Habitat: the locality or environment in which an animal or a plant lives.

Hydrological cycle: the cycling of water from the atmosphere to the earth (precipitation) and back to the atmosphere (evaporation and plant transpiration). Runoff, surface water, groundwater, and water infiltrated in soils are all part of the hydrological cycle.

Hypolimnion: the lower, cooler layer of a lake during thermal stratification. Below the epilimnion and the thermocline.

Inorganic: material which does not contain carbon.

Invertebrates: animals without backbones, eg. insects.

Littoral zone: that portion of a water body extending from the shoreline to the greatest depth occupied by rooted plants.

Macrophyte: rooted or floating aquatic plant.

Nutrient: any element used or required by an organism, including carbon, nitrogen, phosphorus.

Oligotrophic: lakes relatively low in nutrients and plant productivity and with high transparency.

Organic: derived from, or showing the properties of a living organism.

PAH: Polycyclic Aromatic Hydrocarbons.

Pathogen: a microorganism capable of producing disease.

PCBs: Polychlorinated Biphenyles.

Pelagic zone: the open area of a lake, from the edge of the littoral zone to the center of the lakes.

pH: measure of the concentration of hydrogen ions, ranging from pH 1 (very acid) to pH 14 (very alkaline). pH 7 is neutral.

Photic zone: the illuminated region of a lake where photosynthesis takes place.

Phytoplankton: microscopic algae that float freely in open water.

Plankton: small plants (phytoplankton) or animals (zooplankton) drifting with the surrounding water.

Primary production: fixation of inorganic carbon by organisms able to utilize inorganic sources of carbon as starting materials in the formation of organic compounds by living organisms by the use of sunlight.

Profundal zone: mass of lake water below the depth of light penetration.

Residence time: the amount of time required to completely replace a lakes current volume of water with an equal volume of "new" water.

River system: the pattern of tributaries joining one another to form the main river.

Secchi depth: a measure of the transparency of water. Obtained by lowering a white disk into the water until it is no longer visible.

Sediment: bottom material in a lake.

Seepage lake: lake having either an inlet or an outlet, but not both, the water in which is generally derived from groundwater and rain.

Submerged plant: an aquatic plant which has leaves under the surface of the water.

Terrestrial: relating to the earth.

Thermocline: layer of water of rapidly changing temperature in lakes. Between the epilimnion and the hypolimnion.

Trophic state: the degree of eutrophication of a lake.

Zooplankton: microscopic animals that float freely in open water.

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