GUIDELINES of LAKE MANAGEMENT

Volume 8

The World's Lakes in Crisis

Editors:
Sven Erik Jørgensen & Saburo Matsui

Assistant Editor: Joe Banerjee

International Lake Environment Committee
United Nations Environment Programme

International Lake Environment Committee Foundation
1091 Oroshimo-cho, Kusatsu, Shiga 525-0001 Japan
TEL : +81-77-568-4567
FAX : +81-77-568-4568
e-mail : info@mail.ilec.or.jp
URL : http://www.ilec.or.jp/

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FOREWORD

Natural lakes and manmade impoundments (reservoirs) represent major features of the terrestrial landscape. Natural lakes were created in a number of ways, an example being glacial scour of the terrestrial landscape, resulting in creation of depressions in the land surface which subsequently filled with water. Some lakes are enormous in size or volume. Indeed, the North American Great Lakes, Lake Baikal in Russia, and Lake Victoria in Africa can easily be seen from the space shuttle. In contrast, small artificial lakes (reservoirs) were first constructed over 4000 years ago, primarily as a means of irrigation in Egypt, Mesopotamia and China. The first large reservoirs began operation only in the early decades of this century, and have since become major features of the landscape in many places.

Both natural lakes and reservoirs share similarities, and at the same time, can exhibit major differences in their hydrology, biology and chemistry. Most of our limnology, as well as our relevant experience in managing the water quality of lakes, has been developed from studies of natural lakes in such locations as central Europe and the northcentral United States. In contrast, we know much less about reservoir limnology. Indeed, management experience gained from natural lakes has in some cases been extrapolated and applied uncritically to the management of reservoirs. This situation can readily result in significant management problems. For example, the ability to selectively withdraw water from different layers in a reservoir, thereby promoting "short-circuiting" of inflowing waters, can significantly alter the water quality of reservoirs. It also has implications for the biology, chemistry and ecosystem structure and function of the waterbody.

Natural lakes exist as a result of natural processes. In contrast, reservoirs are artificial waterbodies, typically constructed by humans because of problems of either too much or too little water. For areas subject to floods, reservoirs represent features that can safely contain the excessive inflows of water, thereby ensuring they do not destroy human life or property downstream. In arid or semi-arid regions, reservoirs store water that enters it during one time of the year for human uses (e.g., irrigation, drinking) at a later time.

Both natural lakes and reservoirs are subject from similar problems. Examples are water pollution from municipal and industrial effluents and nonpoint source runoff, eutrophication, acidification and ecosystem disruption. Information and experiences on the effective management of such problems, therefore, is essential to ensure the maximum beneficial use of these water resources for human purposes.

A major purpose of this report, therefore, is to facilitate this exchange of information and experience. Although not exhaustive, this report attempts to provide information and guidance on relevant issues related to natural lakes and reservoirs, citing case studies to illustrate its major points. It examines such issues as climate change, acidification and eutrophication, and their impacts on natural lakes and reservoirs. It is the hope of the authors that these experiences will provide useful information to other individuals and agencies responsible for managing these important waterbodies in a scientifically-sound and environmentally-sustainable manner. As the "environmental conscience" of the United Nations System, this is UNEP's wish as well.

Jorge E. Illueca, Assistant Executive Director, Environment Programme

FOREWORD

We have already published six books in the series of Guidelines of Lake Management. These include, Vol. 1 - Principles of Lake Management, Vol. 2 - Socio-Economic Aspects of Lake Reservoir Management, Vol. 3 - Lake Shore Management, Vol. 4 - Toxic Substances Management in Lakes and Reservoirs, Vol. 5 - Management of Lake Acidification, and Vol. 7 - Biomanipulation in Lake and Reservoir Management. This Guideline Book, Vol. 8 - The World's Lakes in Crisis, is different from the other books , focusing on major issues of lakes and reservoirs in the global perspective.

The authors intend to describe issues of impact of global warming on lakes and reservoirs, acidification of the Scandinavian lakes, main problems in Chinese lakes and their restoration, environmental problems of Lake Nasser-Nubia, water quantity and quality relationship for human uses of reservoirs, and the results of survey of the state of world lakes. Those subjects do not cover other important issues such as contamination off hazardous micro-pollutants of industrial, agro-chemical, medical and household uses, and protection of biodiversity in lake/reservoir ecosystems. However, the editors wish to draw public attention to lake and reservoir problems in the global perspective. People have a tendency to look at their lake/reservoir problems as local and specific. Their problems are not local and specific, but very common from a global viewpoint. We are facing all types of common problems such as global warming impacts. Global warming will lead to a state of instability of conditions of both water quantity and quality with lakes and reservoirs. It is very difficult to precisely predict such unstable conditions and risk of each lake and reservoir in the different continents.

The editors describe their views in dialogue format at the end of this book, which readers may find useful to begin with to develop an overall view of problems of lakes and reservoirs around the globe. The editors especially hope that this book will be read by decision makers of economic and environmental development over fresh water resources. Water quantity and quality problems are derived from human activities in the catchment area. Water resources projects should be well coordinated with any land development projects. In this context, this book may help those decision makers to better understand Chapter 18, "Protection of the quality and supply of freshwater resources: Application of integrated approaches to the development, management and use of water resources", of Agenda 21 of the Rio Conference, 1992.

Sven Erik Jørgensen & Saburo Matsui

AUTHORS

James P. Bruce
Chair, Canadian Climate Program Board

Sven Erik Jørgensen
Royal Danish School of Pharmacy
Copenhagen, Denmark

Yan Jingsong & Zhang Yushu
Nanjing Institute of Geography and Limnology,
Chinese Academy of Sciences

Genady N. Golubev
Moscow State University, Russia

B. Entz
Balaton Limnological Research Institute,
Hungarian Academy of Sciences

Ernst A. Nusch
Ruhr River Association
Chem. & Biol. Laboratory
Essen, Germany

Tatuo Kira
Vice Director General, ILEC Board of Directors

Saburo Matsui
Director, Research Center for Environmental Quality Control,
Kyoto University, Japan

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CHAPTER 1

IMPACT OF CLIMATE CHANGE ON LAKES AND RESERVOIRS

James P. Bruce

1.1 THE GREENHOUSE GASES

After several years of sometimes confusing media attention to climate change, it is probably useful to recall a few of the basic facts about the Earth's radiative budget and the changes being brought about by human activities. The so-called "greenhouse effect" is a natural phenomenon whereby water vapour and a few radiatively active trace gases, such as CO_2, in the atmosphere permit solar radiation at short wave lengths to reach the earth, but inhibit some of the long-wave radiation from the earth escaping to space. Without this natural phenomenon, Earth would be some 33°C colder on average and largely uninhabitable. Human activities are greatly increasing atmospheric concentrations of greenhouse gases, some that are effective at wave lengths at which water vapour is transparent. This increasingly inhibits the terrestrial radiant energy from leaving the atmosphere, and results in warming of the atmosphere near the Earth's surface.

The most important of the greenhouse gases, which are augmented by or introduced by human activities, are: carbon dioxide (CO_2) from burning fossil fuels and land use changes; the chlorofluorocarbons (CFCs), used in spray cans and refrigeration, and which also degrade the stratospheric ozone layer. Others of significance but of somewhat lesser importance are methane (CH_4), from agriculture, energy activities and dumps; nitrous oxide (N_2O), mainly from energy sources and fertilizers; and tropospheric ozone (O_3), mostly arising indirectly from vehicles and industry. The concentrations of these gases have been growing at increasingly rapid rates since the beginning of the industrial revolution, and for CFCs, since they were introduced in the 1950s. They are now increasing at compound rates of about 1/2 % per year for CO_2, about 1% per year for CH_4 and tropospheric ozone and in the 1980s about 5% per year for the main CFCs. These contaminants are well mixed throughout the global atmosphere. Their combined radiative effect will be equivalent to a doubling of pre-industrial CO_2 concentrations by as early as 2030 if no additional remedial actions are taken by the world community. These are very rapid changes indeed compared to the long term natural fluctuations in atmospheric composition of the past several hundred thousand years. They are expected to produce equally rapid changes in global climate.

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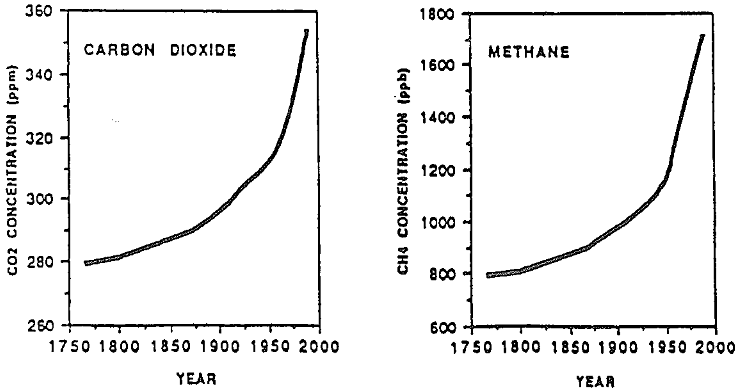
*This article was originally written in May 1991.

Table 1.1 Greenhouse gases and their sources

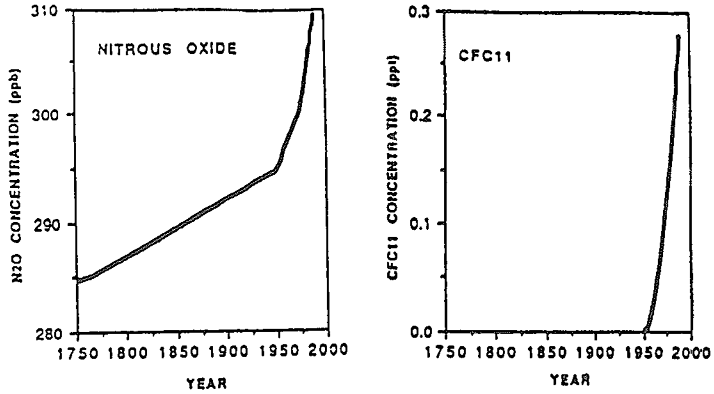
THE PRINCIPLE GREENHOUSE GASES

GAS		CO_2	CH_4	CFC-11	CFC-12	N_2O
Concentration	Pre-industrial	280 ppmv	0.79 ppmv	0	0	280 ppbv
	Present	353 ppmv	1.72 ppmv	280 pptv	484 pptv	310 ppbv
Lifetime in atmosphere	(Y)	(50-200)	10	65	130	150
Contribution to total radiative effect 1980-1990	Per cent	55	15	24(all CFCs)		6

Data from IPCC Working Group I. First Assessment Report 1990.

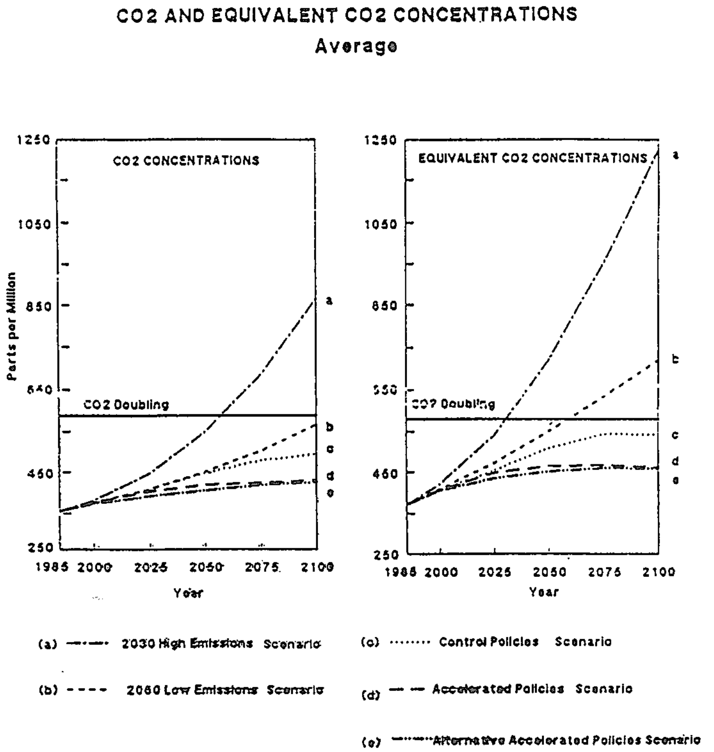


Concentration of carbon dioxide and methane after remaining relatively constant up to the 18th century, have risen sharply since then due to man's activities.



Concentration of nitrous oxide have increased since the mid-the 18th century, especially in the last few decades. CFCs were not present in the atmosphere before the 1930s.

Fig. 1.1 Increases in greenhouse gases



Data from IPCC Working Group I. First Assessment Report 1990.

Fig. 1.2 Projections of increases of CO_2 and CO_2 equivalent, BaU

1.2 MODELLING GLOBAL WARMING

Such changes are projected by means of General Circulation Models, or Climate System Models, which simulate mathematically the climate system, atmosphere, oceans, hydrologic cycle, ice. The Intergovernmental Panel on Climate Change in its Scientific Assessment volume (1990), identified three of these models as "second generation models", with much higher resolution than earlier models, and more sophisticated modelling of ocean-atmosphere interactions and other processes. These three are the 1989-90 model versions of the Canadian Climate Centre, Toronto (CCC), the Geophysical Fluid Dynamics Laboratory (GFHI), Princeton, U.S.A., and the United Kingdom Meteorological Office (UKHI). These models are first verified by ensuring that they simulate the present climate reasonably well, and are then run with a radiative forcing equivalent to a doubled CO_2 concentration in the atmosphere, and the system allowed to come to a new equilibrium. The projected increase in global mean temperature from these experiments is 3.5°C to 4°C using these three models to simulate a doubled CO_2 atmosphere. When ocean induced lags are taken into account the IPCC estimates a 0.2°C to 0.5°C increase per decade over the next century for global mean temperature under a "business as usual" scenario, i.e. no major controls on greenhouse gas emissions except those already agreed internationally, to reduce CFCs for protection of the ozone layer.

Table 1.2 GCM Model Characteristics

Some Differences between Models

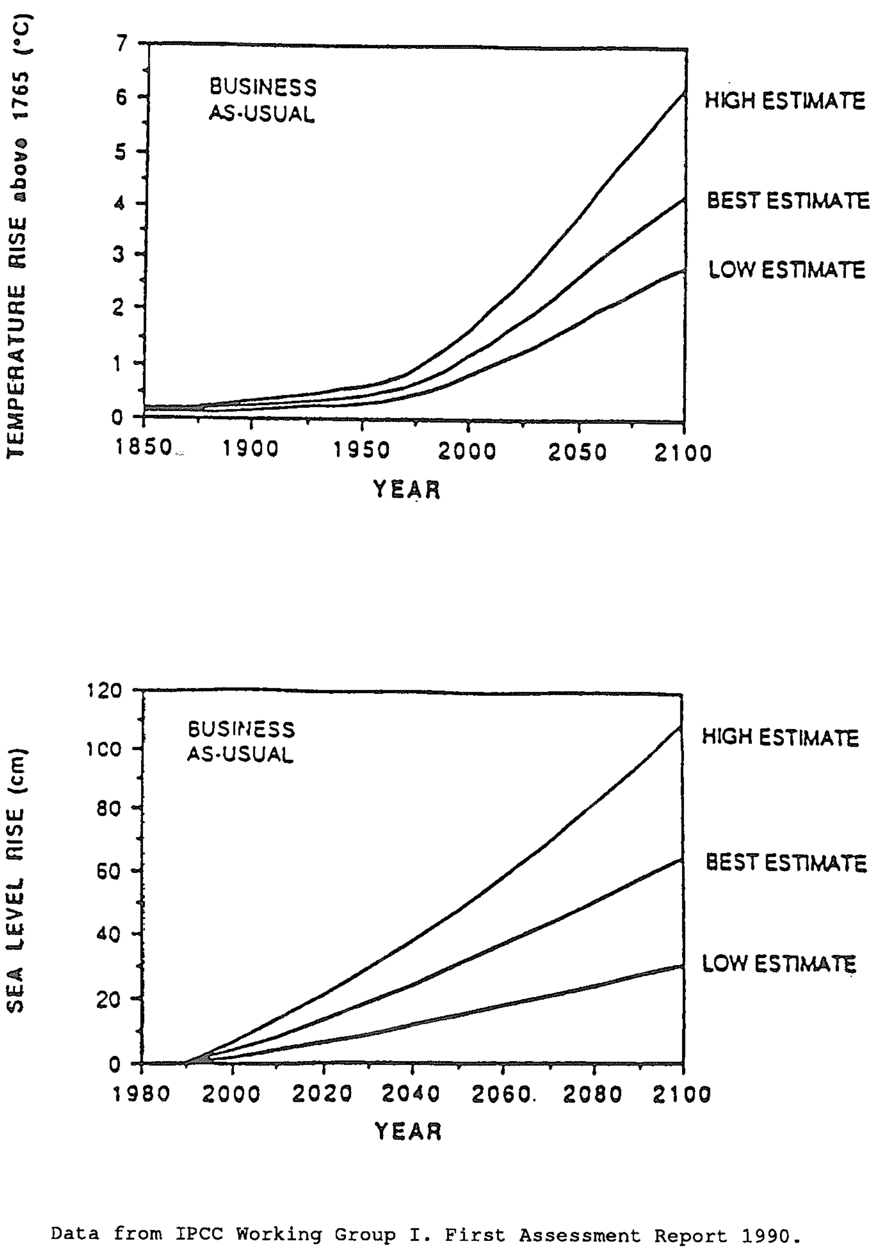
2x CO_2 with Mixed Layer Ocean

Models	Resolution	Diurnal Cycle	Parm Ocean Transport	Under Ice Transport	Optical Properties Feedback	Special Applications Data set
First Generation						
GFDL(1988)	L9, R15	No	No	No	No	No
GISS(1984)	L9, 8°x10°	Yes	Yes	No	No	No
NCAR(1984)	L9, R15	No	No	No	No	No
UKMO(1987)	L11, 5°x7.5°	Yes	Yes	No	No	No
OSU(1988)	L2, 4x5	No	No	No	No	No
Second Generation						
CCC(1989)	L10, T32 (3.75°x3.75°)	Yes	Yes	Yes	Yes	Yes
UKMO(1989)	2.5°x2.5°	Yes	Yes	No	No	No
GFDL(1989)	L9, R30	No	Yes	No	No	No

GFDL Geophysical Fluid Dynamics Laboratory
GISS Goddard Institute for Space Studies
NCAR National Center for Atmospheric Research
UKMO United Kingdom Met. Office
OSU Oregon State University
CCC Canadian Climate Center

It should be noted that these estimates may be conservative since the aggregate of present national projections of CO_2 and CH_4 emission yields a global projection 10-20% higher than "business as usual". Also the mathematical climate system models do not take into account all of the feedbacks in the system, especially the biological ones. The Second World Climate Conference, Geneva, Nov. 1990, concluded that "it appears likely that as climate warms these feedbacks will lead to an overall increase rather than decrease in greenhouse gases". This means that the greenhouse effect and warming may well be under-estimated by the models.

Sea level is expected to rise by 3-10 cm/decade under the "business as usual" scenario with an increase of 65 cm plus or minus 35 cm by the end of the coming century. Agreement is not as close between models, on precipitation changes, although all models show greater global precipitation (by from 3 to 15%) and increased vigour of the hydrological cycle with rising temperatures.



Data from IPCC Working Group I. First Assessment Report 1990.

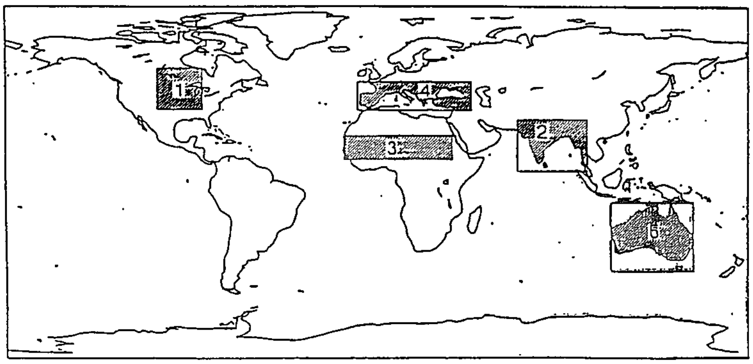
Fig. 1.3 IPCC estimates of global mean temperature increases, BaU

More specifically, the CCC model output (Boer, et al.) shows an annual global average increase of over-land precipitation by 0.9%, an increase of evaporation by 3.8%, with average soil moisture declining by 6.6%, (4.8% Dec-Feb, and 9.1% June-Aug). The geographical distribution of the changes in precipitation are not very consistent from one model to another, but for illustration, the CCC output shows Dec.-Feb. precipitation much lower in northern Mexico and southern U.S.A., in southern Africa and S.E. Asia with increases on the west coast of North America, western Europe and northern Australia. In the northern hemisphere summer, projections are for lower precipitation over nearly all of Europe and northern Africa, North America, central former U.S.S.R. and S. E. Asia with much increased rainfall in the Himalayan region and the horn of Africa. Illustrative outputs, from the CCC model, show soil moisture declines in Dec-Feb projected for southeastern North America, for northern South America, for southern Africa, and for China and south eastern Asia. In June-Aug these moisture deficit areas persist and are added to by most of central and southern Europe and the former U.S.S.R., and eastern Australia. Much moister conditions would prevail in India and Bangladesh in summer.

These regional details of the model outputs have a large degree of uncertainty and there are significant differences in regional projections from model to model. In spite of the difficulty of taking these projections to a regional scale with confidence, the Intergovernmental Panel on Climate Change selected 5 regions to examine in greater detail with outputs from all models. These were:

(1) Central North America (the grain growing mid-West);
(2) Southern Asia (India and Bangladesh);
(3) the Sahel;
(4) Southern Europe and the Mediterranean basin; and
(5) Australia.

The only consistent patterns of soil moisture from model to model were a summer increase by 5 - 10% in Southern Asia, and declines by 15 - 25% in the growing season in Southern Europe and the Mediterranean, and in Central North America. In the two other regions, the Sahel and Australia, the estimates of soil moisture changes are not at all consistent.



Taken from IPCC Working Group I. First Assessment Report 1990.

Fig. 1.4 Map showing the locations and extents of the five areas selected by IPCC

1.3 RESPONSE OF HYDROLOGIC SYSTEMS

River flows and lake levels integrate the effects of the hydrologic parameters at work over various periods, and can magnify to a significant extent the changes in precipitation and evaporation. For example, Nemec and Schaake used the Sacramento hydrologic simulation model (with Kite and Waetatu) for the Nzoia River basin in western Kenya, part of the Lake Victoria system. They found that a 12% increase in evaporation combined with a 25% decrease in annual precipitation would result in a decrease of 70% in the present average runoff of 169 mm/yr. These changes of evaporation and precipitation are of a similar order of magnitude to that suggested by the CCC model output for this area for a doubled CO_2 radiative forcing scenario. In another study (McCabe and Ayers) a 15% increase in precipitation was shown to be needed to offset a 4°C increase in temperature in the Delaware River basin. Because of the magnifying and integrating effects of runoff and lake levels, the size of lakes in pre-historic and more recent times has been used as a sensitive indicator of climatic changes and fluctuations.

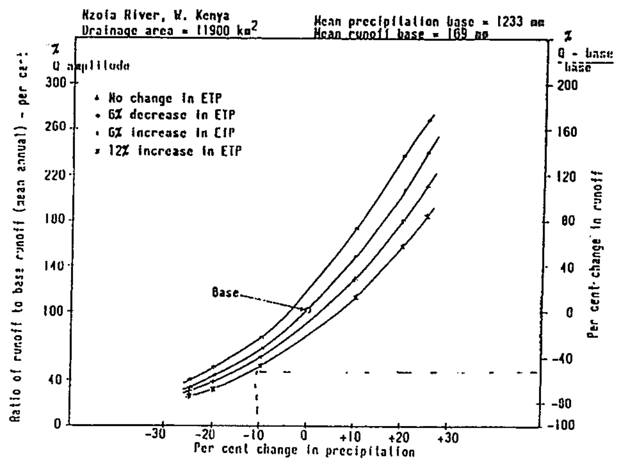


Fig. 1.5 Changes in streamflow as function of changes in precipitation and potential evapotranspiration - Nzoia River. (Nemec and Schaake 1982)

If this is put in terms of reliable yield of a reservoir, Nemec and Schaake demonstrate that, a 1% change in precipitation produces a 2% change in reliable yield from a reservoir storage. They also showed that a 1% change in potential evapotranspiration (closely related to air temperature changes) results in a 0.5% change in reliable yield of a reservoir in a dry area, and a 1% change in a moist region. So lake and reservoir levels are from 2 to 4 times more sensitive to precipitation changes as to changes in evaporation. These results also mean that storage requirements to permit withdrawal of a given proportion of mean annual runoff, increase rapidly if precipitation decreases and evaporation increases. For example, in a humid region, a 25% reduction in precipitation requires a 400% increase in storage for a given sustained withdrawal.

1.4 OTHER FACTORS

It must be emphasized that climate change is only one factor that will affect the behaviour of lakes and reservoirs in the future. Cutting of forests and construction of reservoirs result in increases of streamwater maximum temperatures of a similar order of magnitude to that which might be induced by the global warming likely to occur by the end of the next century. The sediment loads of rivers and reservoirs may be increased in some regions by higher intensity rains of greater frequency in a warmer world, but the dominant factor in controlling erosion and sedimentation will continue to be the vegetation and management of the soils of the basin. Lake levels will continue to be influenced by upstream irrigation water withdrawals or diversions and by direct withdrawals by growing populations. Thus, it is important to place the changes that may arise from global warming in the context of all of the other changes that will affect the lakes and reservoirs of the world of the future.

1.5 LAKES AND RESERVOIRS

(a) Lake Levels

In the light of the sensitivity of lake levels to climatic fluctuations it is not surprising that many of the studies of climate change impacts on lakes have focussed on lake levels. For large lake systems, the North American (Laurentian) Great Lakes and the Caspian and Aral Seas have been a focus of much of this work. The Laurentian Great Lakes have a surface area of 246,000 km^2, about 1/3 of the total drainage basin. This very high proportion of lake surface to land area, results in changes in lake levels that respond directly and quickly to fluctuations or changes in evaporation or precipitation. More than a decade of work has been undertaken on potential impacts of global warming on the Great Lakes. Cohen and Allsopp (1988) and Smith (1991) have summarized the results of these studies. Cohen and Allsopp conclude that use of the "first generation" Goddard Institute for Space Studies (GISS), GCM, outputs for a doubled CO_2 world, indicate that mean lake levels could decline by 0.2 to 0.8 metres, with the flows of interconnecting channels decreasing by up to 20%. The GISS model output gives a relatively conservative estimate of changes. The more recent CCC model and most other models show greater temperature changes and lesser precipitation increases or even decreases in the basin. Croley and Hartmann (1990) indicate much greater declines, with drops in level from 1951-80 averages of up to 2.5 m for Lake Michigan-Huron based on first generation GFDL model outputs. However, the direct effects of precipitation and evaporation changes will be exacerbated by much increased consumptive use of Great Lakes waters, both for growing urban populations, and for more irrigation as temperatures rise. Taking both factors into account, warming and consumptive uses, average lake levels would be lower than the lowest in the 100 year record eight years out or ten. For the climate model outputs giving the smallest changes, this would result in an increase of 30% in shipping costs, due especially to reduced drafts in connecting channels and to a loss of 4,000 gigawatt-hours of hydro-power generation at Canadian plants alone.

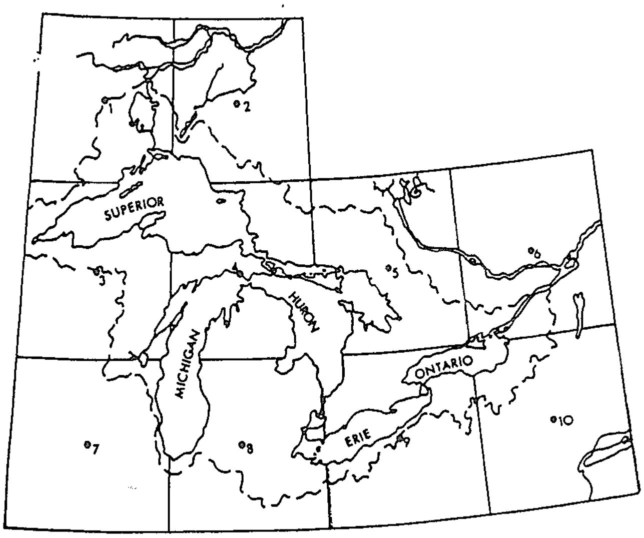


Fig. 1.6 Map of Great Lakes basin

YEARLY MEAN LEVELS – LAKE ERIE

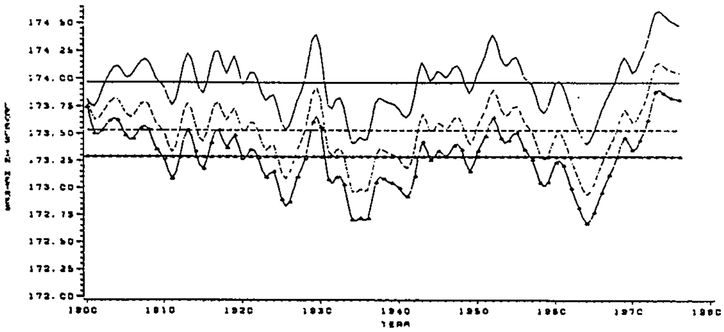


Figure 6. Lake Erie Yearly Mean Levels 1900 - 1976

———— Basis of Comparison

- - - - - - Climatic Change

•—•—• Climatic Change plus Consumptive Use

Fig. 1.7 Lake Erie yearly meanlevels 1900 - 1976 (GISS; Sanderson)

The Aral and Caspian Seas are in regions where the CCC model output suggests significantly greater soil moisture (and probably runoff) in the period December to February, and significantly less in summer (June, July and August). This suggests the possibility of greater annual fluctuations in level and further summer declines. The Aral Sea has dropped some 14 metres over the past 30 years, due mainly to extensive use of waters of influent rivers for irrigation, but partly to dry climatic conditions. The climate projections reinforce the urgency of remedial actions.

Lake Chad has similarly shrunk from 23,500 km^2 in the 1960s to 2,000km^2 in 1985, with Sahelian rainfall reduced to 62% of normal (1901-85) in the period 1970-79 and 50% of normal in 1981 to 1984. Lake Chad levels in the 1980s were some 5 metres lower than a century earlier. In this region a precipitation decrease of 9 to 24% resulted in a runoff reduction of 15-59% (Sircoulon, 1987). The second generation GCMs suggest little change from average precipitation values in this region for a doubled CO_2 atmosphere. However, the projected 1-3°C warming would result in even stronger moisture stresses on vegetation and greater evaporative losses.

Laguna de Bay adjacent to Manila in the Philippines, is the largest freshwater lake in area (90,000 ha) in Southeast Asia. This relatively shallow lake (average depth 2.8 m), provides many services to the densely populated region-water supply, fisheries, irrigation, water, hydro power, industrial source, etc.. The CCC model output with a doubled CO_2 climate suggests much lower rainfall in winter and slightly lower in summer. One other second generation model GFDL High Resolution gives more optimistic results. However, if such decreases in precipitation do occur, a resulting lowering of lake level could have devastating economic impacts in the Manila region.

In other areas, mean reservoir levels in the Tennessee Valley Authority's system were estimated to drop as much as 9 metres if the GISS model outputs for a doubled CO_2 were realized.

In 1991 after three years of drought, and extensive use for agriculture, the waters of Lake Kinneret (the Sea of Galilee) are now below the level at which water can safely be pumped. This is in the Mediterranean basin for which IPCC projects significant summer drying with a 2 x CO_2 atmosphere.

In some regions lake levels may well rise instead of decline. This is especially so in Southern Asia (5° to 30° N. - 70° to 105° E.) and in northern North America, where there are consistent outputs from the various models indicating increased precipitation and soil moisture. For the Indian sub-continent and adjacent regions, the precipitation increases range from 5 - 15% in summer with little change in winter. For lakes and reservoirs in the region this suggests increasingly abundant water supplies for irrigation, energy production, etc., but greater frequency of damaging floods, shore erosion and flooding of marshlands.

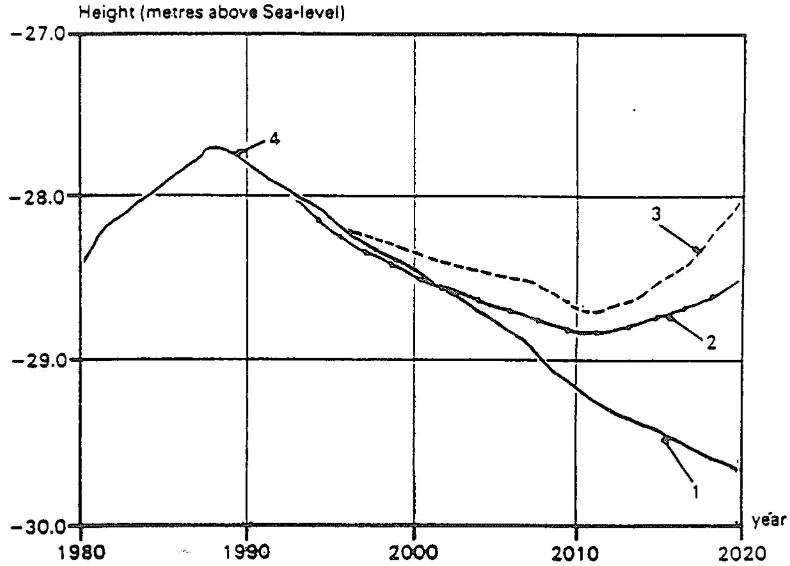


Fig. 1.8 Estimated levels of the Caspian Sea, 1989 - 2020 under varying climate change scenarios: 1 - stationary climate with man's impact. 2 - model-based anthropogenic change in climate including man's impact, 3 - map-based anthropogenic change in climate including man's impact, 4 - observed lake level variations before 1988. (IPCC 1990)

A note of caution must be sounded, however, about expecting too close a correlation between lake levels and fluctuations of climatic variables. For short term fluctuations in climate, lake levels may well tend to even out the variations rather than magnify them, depending on the response time of the lake basin. It is only when long term trends in climate are observed or considered that "the running integral of net precipitation processes" provided by the lake level fluctuations becomes a valuable indicator of climatic change (Klemes and Nemec). Rivers flowing from large lakes or reservoirs tend to exhibit the same kind of long-term "memory" of the net processes at work.

(b) Water Temperatures and Chemical Budgets

In lakes of temperate regions, the most profound changes will be in the duration and intensity of summertime thermal stratification, with increased surface water temperatures strengthening the thermocline between the upper epilimnion, and the hypolimnion. Empirical relations developed during the International Biological Programme, but strongly biased towards lakes in the northern hemisphere, show that incident solar radiation is the dominant factor in the seasonal march of lake surface temperatures. The sensitivity of the climate system models is not great enough to project with any confidence the changes in cloudiness (high and low cloud) in a warmer world so projections of lake temperatures in any quantitative way cannot be undertaken with confidence as this stage.

However, recent work by Schindler et al., provides a valuable analysis of data from the Experimental Lakes Area of Northwestern Ontario, Canada. In the 20 years of record, air temperatures have increased an average of 2°C, the magnitude of average temperature change projected globally for early in the next century, "a preview for other regions". This has resulted in lake temperature increases averaging 2°C. Precipitation and runoff to the lakes also declined significantly during this period, reducing dramatically the rates of water renewal. This decrease has resulted in increases in total dissolved N (nitrogen) and in conservative ions. During the latter part of the 20 year period, increased forest fire incidence in the watershed, with drier conditions, complicated significantly the chemical inputs to the basins, changing the optical properties of the lakes with less inflow of coloured organic matter. The resulting deeper penetration of solar energy, and observed increases in average wind speeds due to decreased forest cover, caused the thermoclines of the summer - stratified lakes to deepen. While the ELA region is in the area of projected high temperature increases by all second generation climate system model experiments with doubled CO_2, (+6—8°C in winter, +4—6°C in summer), it is still premature to definitively attribute the observed warming to the effect of greenhouse gas increases. Nevertheless, the trends are consistent with global warming projections and the nature of lake responses provide valuable insights about responses of temperate region lakes.

The longer period of thermal stratification with a warming climate evident in the small lakes of the ELA region is also expected in large lakes of the temperate zone. For example, Lake Michigan would experience a stratification season as much as 2 months longer than at present, and the lake may not fully turn over in winter, with the likely development of a permanent thermocline below the shallow seasonal thermocline. In all such deeper lakes of temperate regions the longer stratification season would mean increases in hypolimnetic dissolved oxygen depletion, with resulting adverse effects on cold-water biotic communities (see next section). The thermal structures of the lower Great Lakes (Erie and Ontario) in an exceptionally warm year, 1983, have been examined to help determine the probable impact of a warmer climate (Schertzer and Sawchuk). These lakes in early spring are characterized by a "thermal bar" a narrow lateral thermal barrier between warmer coastal waters and colder offshore waters initially at 4°C or maximum density. The "thermal bar" acts as a barrier to transport and dispersion of pollutants and other material from shoreline areas to the main body of the lake (Rodgers). In 1983 the mean air temperature at Toronto's International Airport near Lake Ontario was 3°C to 4°C above average for the period December (1982) to March, and the date of full stratification and disappearance of the 4°C isotherm in the deepest part of Lake Ontario was some 4 to 5 weeks earlier than normal with earlier dispersion of near-shore pollutants to the main lake body. This gives some indication of the thermal regime of the lakes under a doubled CO_2 scenario, since the CCC model suggests an increase of about 4°C+ in Dec.-Feb. temperatures for the Lake Ontario basin.

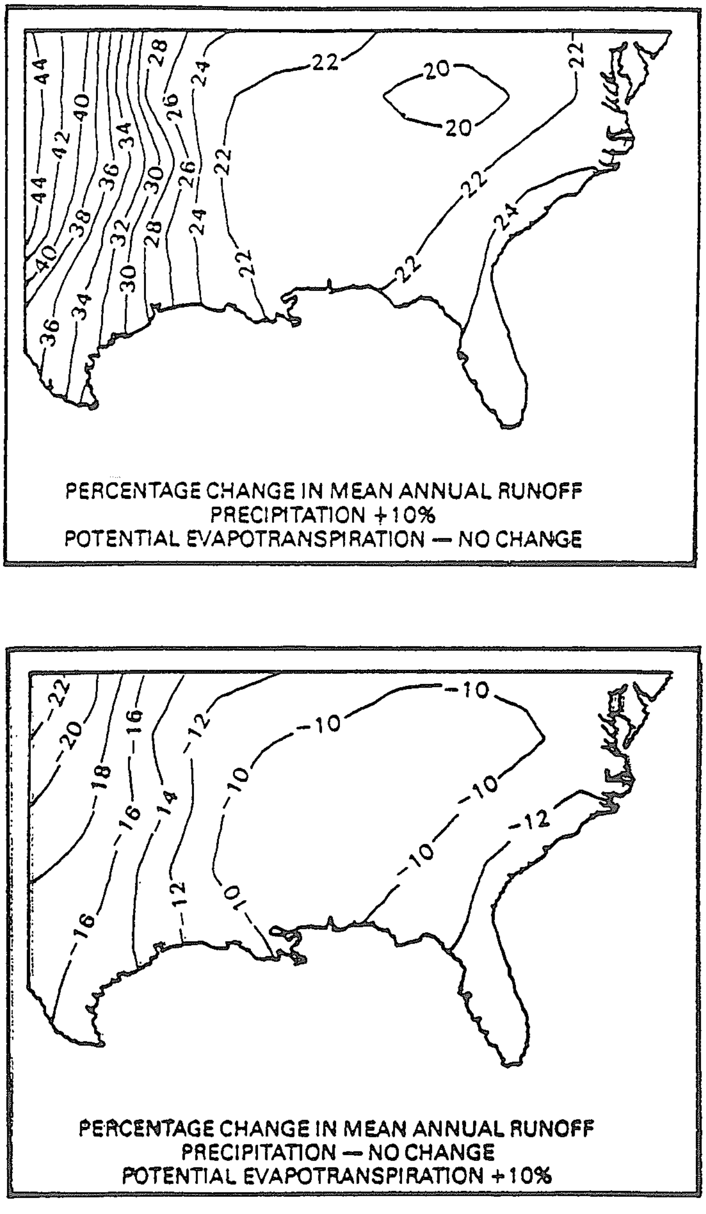


Fig. 1.9 Percentage changes in mean annual runoff by varying precipitation (upper) and potential evapotranspiration (lower). (Schaake, 1990)

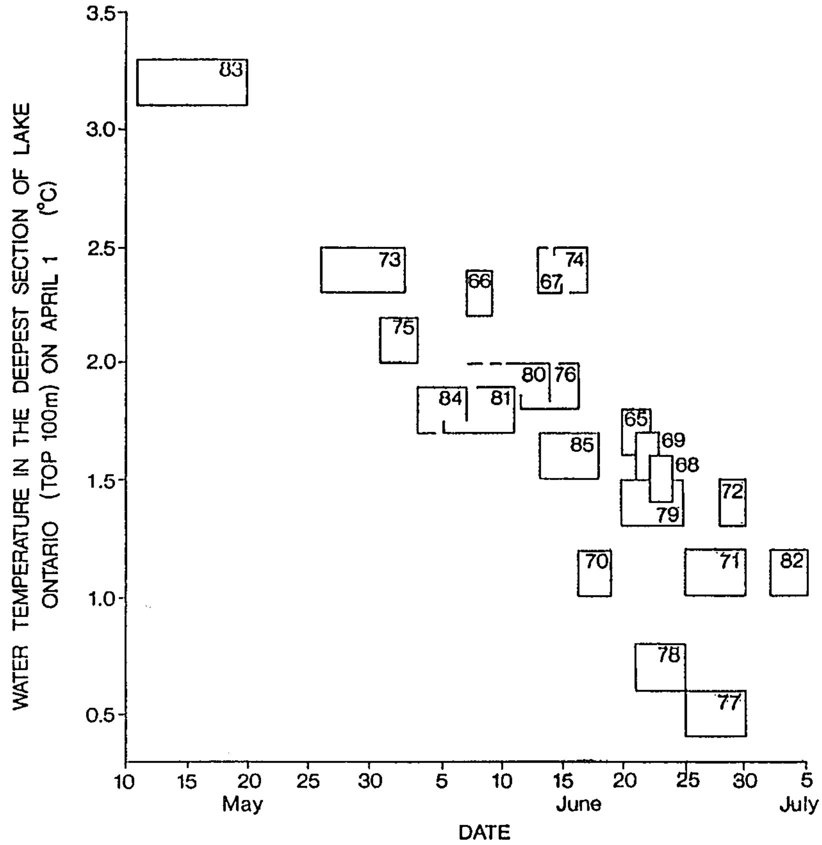
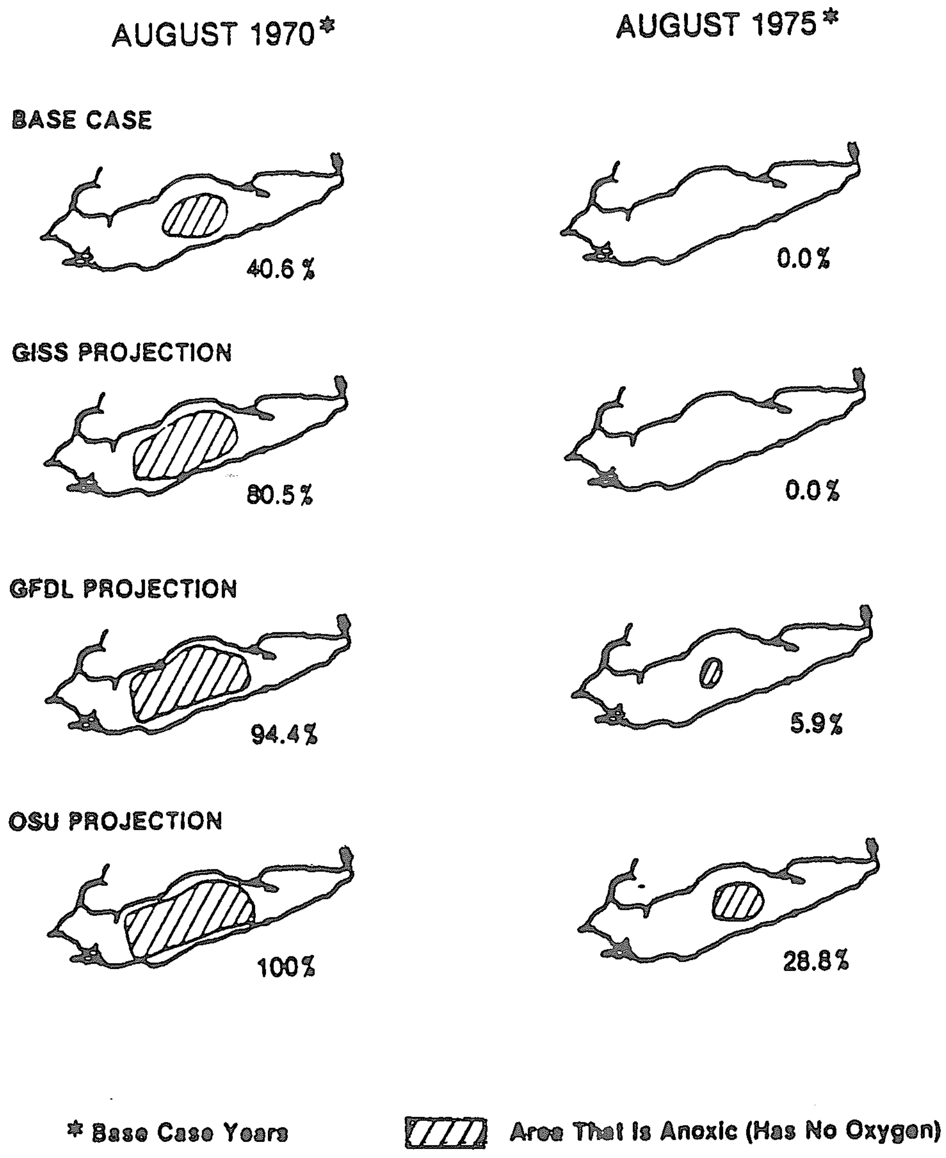


Fig. 1.10 Date of full stratification or disappearance of the surface 4°C isotherm as a function of the April 1 water temperature in deepest basin of Lake Ontario just east of 77 45'W. (Schertzer and Sawchuck 1990)

(c) Lake Water Quality and Biological Effects

Studies of global warming impact on dissolved oxygen in Lake Erie were undertaken through use of a hydrodynamic-water quality model. With first generation climate model outputs and doubled CO_2 values as inputs, it was concluded that the lakes' central basin would be stratified for a 2 to 4 months longer period and that both upper and lower layers of the Central Basin would have less dissolved oxygen, by 1 mg/l average in the upper parts and 1-2 mg/l in lowest layers. A marked increase in the anoxic area in the bottom waters of the central basin was also projected, due in part to the increase in the stratified period, but also to increased biological productivity and microbiological activity in the sediments with higher lake temperatures overall. Degraded quality of hypolimnetic waters could have markedly adverse effects on cold water fish and on release of hydrogen sulfide, methane and toxics from the sediments. In short, global warming will increase the rate of eutrophication of lakes and reservoirs.



Source: Blumberg and Di Toro

Fig. 1.11 Area of central basin of Lake Erie that becomes anoxic under doubled CO_2 scenarios.

While these effects in temperate region lakes on fisheries may be negative, there are positive aspects for fisheries as well. Higher water temperatures result in higher metabolic rates and shorter egg incubation periods for many fish species (Regier, Holmes and Pauly). In addition growth rates in both mass and numbers of algae, protozoa, stonefly nymphs, and common carp are all highly correlated with temperature. With lower rates of water replacement in regions with lower streamflows in a warmer climate, and the increase in productivity, rates of eutrophication would accelerate.

There would, of course, be changes in species distribution with cold-water species thriving closer to the poles and being gradually replaced by warmer water species in temperate zones. Higher water temperatures also limits the viability of various aquatic populations, for example egg development of perch and smallmouth bass is seriously inhibited at temperatures above 20°C, and salmon spawning and egg development above 13°C.

The gradual warming of lakes inferred by the global warming projections would also result in poleward movement of water-borne or water-connected diseases which are temperature limited. Water is the principal transmission agent for 80% of the diseases of the tropics. For example, yellow fever transmitted by mosquitoes is highly temperature-dependent. Epidemics occur only in areas with annual temperatures greater than 20°C. Similarly the snails which transmit schistosomiasis only survive in water temperatures from 18-35°C. The poleward spread of warmer water temperatures would similarly spread these diseases and others such as malaria, hook worm infections and so on.

One factor sometimes overlooked in considering the loading of toxic chemicals and nutrients to lakes is the contribution of precipitation and dry fall from the atmosphere to the chemical budget. The 1991 report of the GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Pollution) addresses the question of climate change and the sea/air exchange of chemicals. Many of the GESAMP conclusions concerning marine areas and nearly enclosed seas like the Mediterranean apply as well to lakes, especially larger ones. The report concludes that in the western Mediterranean nitrogen inputs from the air and the rivers are approximately equal, and for the North Sea "one third of the nitrogen input is from the atmosphere, most of it pollution derived". The micro-nutrient iron is mainly atmosphere-transported to water systems. Nitrogen oxide emissions are growing rapidly in developing regions, and could have marked effects on productivity of both freshwater and coastal marine ecosystems. Earlier work by GESAMP had shown that phosphorous and trace metal (lead, cadmium and mercury) loadings from the atmosphere to the Mediterranean were greater than from loadings from riverine sources or direct discharges. Similar results have been found for the Great Lakes, with the atmosphere being a dominant source of nitrogen, lead, PCB's and a significant proportion of the total loadings of phosphorus and many toxic substances. However, as the GESAMP report points out - future climate change may alter atmospheric circulation and thus the source regions and transport paths for these atmospheric contributions to nutrient and toxic chemical balances. Unfortunately, the present state of climate system modelling does not yet permit prediction of the specific nature of such changes in atmospheric circulation and pollutant deposition.

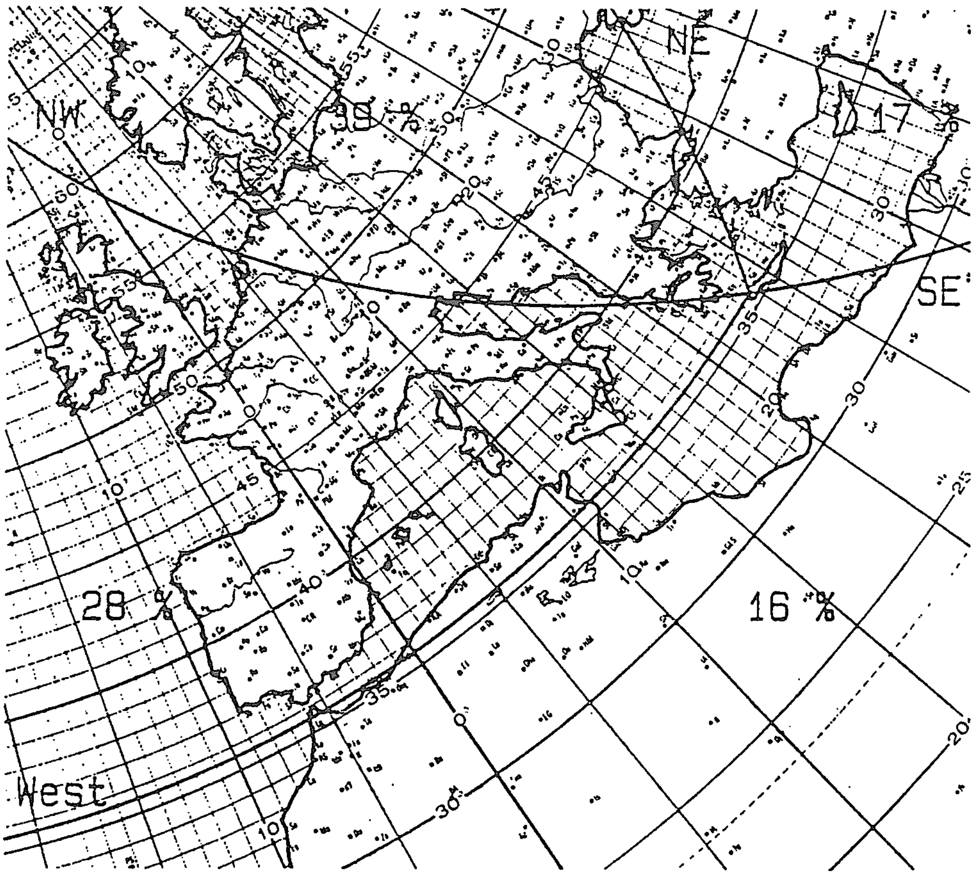


Fig. 1.12 Crete trajectories shown on an annual percentage basis for west, northwest, northeast and southeast sectors. (GESAMP)

(d) Effects on Ice Regimes

Lakes freeze from the top down because the heaviest water is at 4°C and the lighter surface water in prolonged cold spells is at 0°C. During the winter, lake ice and snow prevent oxygen regeneration from the atmosphere, almost eliminate inflow and outflow and disrupt photosynthesis. Very prolonged ice-covered periods result in oxygen depletion and at times anoxic conditions with resulting releases of hydrogen sulfide, methane, CO_2 and ammonia from the decomposition processes in the sediments. Winter anoxia will be much less prevalent at a given latitude with a warmer climate and shorter ice-bound seasons.

In the Experimental Lakes Area in northwestern Ontario, the ice free season increased by about 20 days with the 2°C warming of climate from 1970-90, mainly due to earlier spring break-up. In the Great Lakes the average maximum ice cover with a doubled CO_2 climate is projected to drop to 0% from the present 33 to 72%, except for shallower Lake Erie where the average maximum would decrease from 90% cover to 50% (Sanderson). In addition to the water quality benefits, these changes would be of major advantage to the shipping industry. In time, it would mean a major reduction in ice cover over a period of one to three months duration (Smith).

1.6 IMPLICATIONS FOR LAKE MANAGEMENT AND PUBLIC POLICIES

It is clear from this short review of literature on impacts of climate change on lakes and reservoirs, that both adverse and beneficial effects will occur. Management strategies should be directed at capitalizing on the benefits, and minimizing the adverse effects. At this stage of development of predictions of climate change due to increasing greenhouse gas concentrations, major uncertainties exist, especially at a regional level on the geographical scale which directly affects lake and reservoir basins. This does not mean that no adaptive strategies can be developed.

Those especially important for lake and reservoir management can include:

(i) Building greater resiliency into design and operation of reservoir systems. The work of Klemes and others, published by WMO as a contribution to the World Climate Programme, provides some valuable guidance on how this could be done.

(ii) Developing effective preparedness plans for dealing with natural disasters, high water and floods, low waters and droughts. Such plans need to be strengthened in many countries. The U.N.'s International Decade for Natural Disaster Reduction (IDNDR - 1990-9) provides a valuable framework for international coordination of these activities.

(iii) Reducing pollution discharges directly to lakes and inflowing river systems to counteract the effects of accelerating eutrophication. In addition, the large percentage of some nutrients, acidic and toxic substance which are transported by the atmosphere into lakes, sometimes over long distances, dictates that nations move as quickly as possible to

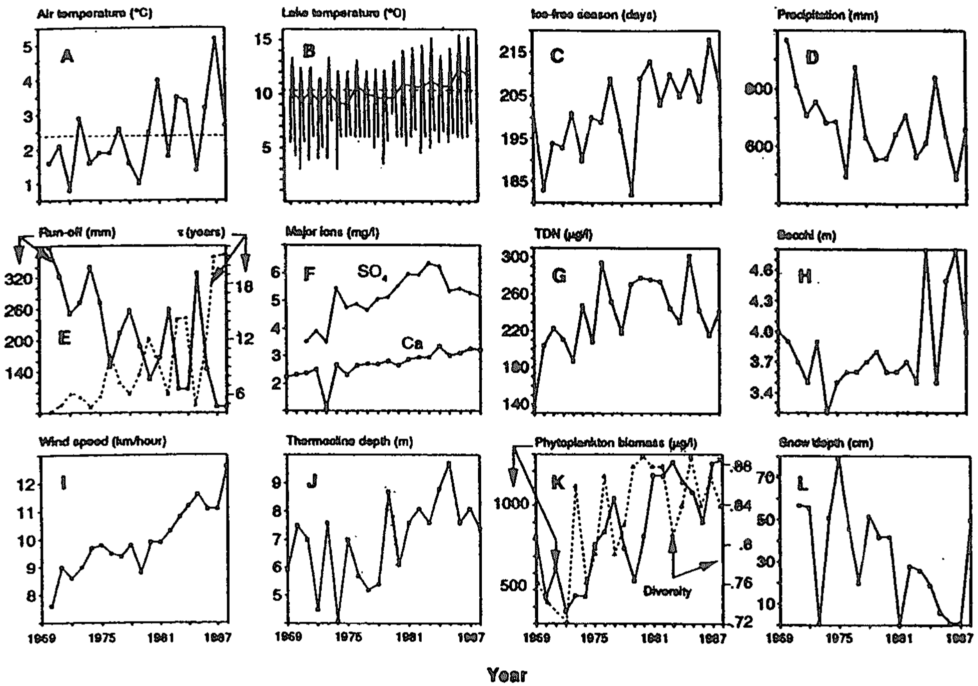


Fig. 1.13 Records of physical, chemical, and biological variable at the Experimental Lakes Area, northwestern Ontario, from 1969 or 1971 thorough 1988. (A) Mean annual air temperature at Rawson Lake meteorological station in the watershed of Lake 239. (B) Volume-corrected average lake temperature of Lake 239 during the ice-free period. Each of the spikes is a plot of monthly water temperatures in the ice-free season for a single year. The jagged line connects means of temperatures from the ice-free season. The horizontal dashed line is the mean temperature for ice-free seasons for entire period. (C) Duration of the ice-free period for Lake 239. (D) Annual precipitation at the Rawson Lake station. (E) Annual runoff from the Lake 239 watershed (solid line) and water renewal time for the lake (↑, the dashed line). (F) Mean annual volume-weighted concentrations of Ca and sulfate in Lake 239. Similar increases were observed in Mg, K, Na, and Cl. (G) Mean annual volume-weighted concentrations of total dissolved N (TDN). (H) Average secchi disc readings in the ice-free season. (I) Average wind speed in the ice-free season measured 10 m above ground at Rawson Lake meteorological station. (J) Average thermocline depth in the ice-free season. (K) Average phytoplankton biomass in the epilimnion in the ice-free season (solid line) and Simpson's index of diversity (dashed line). (L) Snow depth at the end of March in the Lake 239 watershed. (Schindler, *et. al*)

comprehensive international agreements to reduce the pollution burden from the atmosphere to aquatic systems.

(iv) Employing existing and novel technologies for more efficient use of water for irrigation especially in developing countries in semi-arid zones (SWCC).

(v) Supporting monitoring and research programmes to measure and understand climate, the factors that affect it and the impacts of climate variability and change. It is critically important that better assessments be made of climate changes and impacts on natural and economic systems, especially lakes, reservoirs and rivers.

(vi) Of special importance, internationally, in connection with lakes and reservoirs, is support of the Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Program (WMO and ICSU). Only with strong international support of the WCRP and major projects such as GEWEX will predictions of future climate be made more useful in projections of water resources and their quality.

Finally, preventive measures to slow the rate of increase of greenhouse gases are urgently needed and all countries are urged to support the negotiation of a global convention on climate change now underway. The Ministerial statement from 137 countries at the Second World Climate Conference provides for some initial commitments by industrialized countries to a stabilization or reduction of CO_2 emissions. The statement also recognizes the needs of developing countries for financial and technological assistance to move from net deforestation to net afforestation, and to satisfy energy needs with low-emission pathways. These agreed or inferred commitments can form a sound initial basis for an international convention.

The Earth is already committed to a significant amount of global warming through past increases in greenhouse gas concentrations due to human activities. It will take major international efforts to prevent an equivalent radiative forcing of a doubled CO_2 concentration or less within the next four decades. However, without that effort, the world is eventually committed to changes much greater than discussed above, and at rates at which natural systems will not readily adapt. Reasonable stewardship of our small planet requires action now to reduce greenhouse gas emissions and to increase vegetative sinks of carbon dioxide.

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CHAPTER 2

ACIDIFICATION OF THE SCANDINAVIAN LAKES

Sven Erik Jørgensen

2.1 INTRODUCTION

More than 80% of the European lakes can be found on the Scandinavian Peninsula and in Finland. They are all of glacial origin and represent a wide spectrum of lakes with respect to depth and area.

Two unfortunate factors, however, threaten many of these beautiful lakes:

1. With the exception of Denmark and the southern part of Sweden, named Skåne, the ground and surface water in Scandinavia is very soft and has, therefore, a low buffer capacity.

2. The dominant wind direction in Europe is from the Southwest which implies that the acid air pollutants (sulphur dioxide and nitrogen oxides) from the most heavily industrialized area of Europe, Germany, Benelux and Southern England is transported to Scandinavia.

Current examinations of the status of the lakes in Norway and Sweden have revealed that several thousands of lakes with an area of more than 10 ha have a pH of less than 5.0 and hundreds of lakes have a pH close to or even less than 4.0. It is estimated that Sweden has 85,000 lakes, of which 4,000 lakes are classified as seriously acidified (pH $<$ 5.0). 18,000 lakes are acidified during some critical periods, such as snow melt. The water retention time plays, of course, an important role. The largest lakes with the highest retention time have generally not yet been acidified to the same extent as the smaller lakes with short retention time. As many of the largest lakes in Europe are situated in this region, we may only have seen the "tip of the iceberg" and may expect that the problem will get much worse in the coming decades, if the air pollution is not reduced significantly in the most industrialized areas of Europe. Fortunately, measures have been taken in most Western European countries to reduce the emissions of acid pollutants. The emission of sulfur has been reduced since 1980 by more than 50%. Model results have, however, shown that further reduction is required if the adverse effects of acid rains are to be eliminated.

The low pH value of the lake water implies the occurrence of several adverse effects which have been widely observed in many of the Scandinavian lakes:

1. Carbon dioxide is toxic to fish. The ratio of carbon dioxide to hydrogen carbonate is increasing with decreasing pH.

2. Formation of free carbon dioxide will take place at low pH. This may cause such low concentrations of inorganic carbon that carbon may be the limiting nutrient. Unnatural oligotrophy has been observed in many Scandinavian lakes.

3. The fertility of fish and zooplankton eggs is highly dependent on pH. A significantly lower fertility is observed at pH below 4.5-5.0.

Extreme low zooplankton and fish abundance and diversity due to points 1 and 2 have therefore been observed in the acidified Scandinavian lakes.

4. All biological processes have a pH-optimum, which is usually in the range 6-8. It implies that algae growth, microbiological decomposition, nitrification and denitrification all will decrease in acidic water. As a consequence, the cyclical rates of nutrients have been reduced significantly in many acidified lakes.

5. The release of heavy metal ions from soil and sediment increases very rapidly with decreasing pH. Heavy metal hydroxides have very little solubility product, which implies that most heavy metal ions are precipitated at pH 7.5 or above. As most heavy metal ions are highly toxic, increased concentrations of heavy metals have undesirable adverse effects. There are many cases of abnormally high concentrations of heavy metal ions in Scandinavian lakes.

This chapter is concerned with the effect of low pH in the Scandinavian lakes caused by acid rain due to anthropogenic emissions of acid gases. The following sections are concerned with various types of observed effects due to low pH. The second section is concerned with the water chemistry. The third section deals with phytoplankton and macrophytes - the primary producers, while section four is devoted to zooplankton. Section five looks at the effects on planktivorous and carnivorous fish and section six on amphibian and riparian fauna. Section seven, the final section, deals with the effects on the entire ecosystems. All the components - chemical as well as biological - are inter-related. The effects on fish will also have an indirect effect on zooplankton and phytoplankton and even the composition of the water. It is therefore necessary to summarize all the effects and add the indirect effects to get the effects on the entire system.

2.2 OBSERVED EFFECTS ON LAKE WATER CHEMISTRY

A low pH implies that hydrogen carbonate is converted into free CO_2, which is toxic to fish and other animals, as respiration is controlled by the difference between CO_{2-} concentration in the blood and the environment.

The processes involved can be described by the following chemical equations:

$$CO_3^{2-} \xrightarrow{+H^+} HCO^{3-} \xrightarrow{+H^+} H_2O + CO_2 \qquad (1)$$

Particularly low pH-values may be observed after the melting of snow, because the acid accumulated during the winter will be dissolved in the snow water and neutralization due to the contact with the soil is reduced, as the retention time of the water is short and the soil is still frozen. As water has the highest specific gravity at 3.96°C, the very acid water originated from melting of snow will replace the surface water, where pH will be particularly low during the spring time.

The trends observed in many Scandinavian lakes illustrate how fast the acidification process is progressing, as shown in Table 2.1.

The chemical composition of acid surface waters in Scandinavia is a high sulfate concentration (≥ 150 mg/l). Sulphate becomes one of the most dominant anion and replace hydrogen carbonate which is released to the atmosphere according to equation (1).

The solubility of most metal ions increases with decreasing pH; see Fig. 2.1. Elevated concentrations of many metal ions particularly aluminium-, iron- and manganese ions, but also more toxic ions such as cadmium-, copper-, zinc- and mercury ions are therefore observed. The free ions are generally more toxic to aquatic organisms than complex ions. As the formations of most complex ions are decreasing with decreasing pH, the toxicity of most metals will furthermore increase with decreasing pH. The speciation of the metal ions are dependent on pH, as shown in Table 2.2, reproduced from McDonald et al. (1989).

Table 2.1 Acidification of soft-water lakes in Scandinavia and North America

	pH	**pH**	**Average**	
Region	No. of lakes	Early measurements	Recent measurements	change ΔpH/year
Scandinavia				
Central Norway	10	7.3 ± 0.8 (1941)	5.8 ± 0.7 (1975)	-0.05
West coast of Sweden	6	6.6 ± 0.2 (1933-35)	5.4 ± 0.8 (1971)	-0.03
	8	6.8 ± 0.2 (1942-49)	5.6 ± 0.9 (1971)	-0.04
West central Sweden	5	6.3 ± 0.3 (1937-48)	4.7 ± 0.2 (1973)	-0.06
South central Sweden	5	6.2 ± 0.2 (1933-48)	5.5 ± 0.7 (1973)	-0.03
Southernmost Sweden	51	6.76 ± 0.14 (1935)	6.23 ± 0.44 (1971)	-0.015

Aluminium compounds are ubiquitous in geological and biological material. It is always in the trivalent state and forms very stable complexes with a variety of inorganic and organic material. Below pH 5.0 the form Al^{3+} increases progressively and at pH 4.0 it is the major ion present (Stumm and Morgan, 1996). Fig. 2.2 shows the activities of soluble inorganic aluminium species in relation to pH. The overall solubility of aluminium is indicated on the Figure. As seen the lowest solubility ($10^{-7.5}$) is obtained at pH close to 6.0, while the solubility at pH 4.0 is approximately 3,000 times higher. The diagram also shows that at pH-values above 5.0 the soluble hydroxo complexes have higher concentrations than the trivalent ion, Al^{3+}. The primary effect of aluminium on fish is to disturb sodium regulation mechanisms at the fish gill. The present knowledge indicates that the trivalent ion and the hydroxo complexes have a significant effect on the sodium balance of fish already at low concentrations: 50-70 $\mu g/l$.

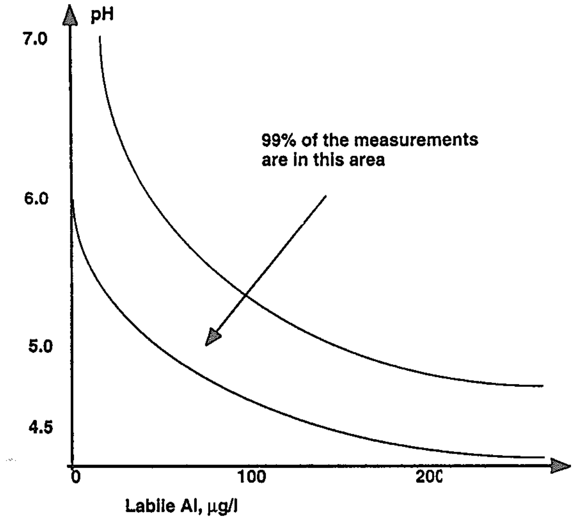

Fig. 2.1 Relationship of measured pH and labile aluminium in an extensive lake data set (from 1000 Norwegian lakes) (after Henriksen et al., 1987).

Slightly higher concentrations may reduce growth (Sadler and Lynam, 1988), impair calcification and result in reproductive damage. The LC-50 value for most fish species is 7.3 mg/l. Complex aluminium forms, other than hydroxo complexes, are not toxic in the relevant concentrations. Invertebrate species are also much less sensitive to aluminium, although similar effects on the sodium balance have been observed on crustaceans.

The concentration in natural fresh waters of aluminium is usually very low, in the range of a few p.p.m. Drainage waters from deforested areas or acid waters (pH < 5.0) have, however, often elevated aluminium concentrations, mainly consisting of Al3+ or complexes with hydroxides, fluoride or sulfate

Table 2.2 Major species of metal ions as function of pH

Metal	pH 7.5	pH 5.0	pH 4.0
Aluminium	$Al(OH)_4^-$	$AlOH^{2+}$, $Al(OH)_2^+$	Al^{3+}
Cadmium	Cd^{2+}, $CdOH^+$	Cd^{2+}	Cd^{2+}
Copper	Cu^{2+}, $CuCO_3$	Cu^{2+}	Cu^{2+}
Iron	$Fe(OH)_2^+$, $Fe(OH)_4^-$	$Fe(OH)_2^+$	$Fe(OH)_2^+$
Lead	$PbCO_3$, $PbOH^+$	Pb^{2+}	Pb^{2+}
Manganese	Mn^{2+}	Mn^{2+}	Mn^{2+}
Nickel	Ni^{2+}	Ni^{2+}	Ni^{2+}
Zinc	Zn^{2+}, $ZnOH^+$	Zn^{2+}	Zn^{2+}

Debate continues as to which aluminium species are toxic. There is some evidence from laboratory studies that $Al(OH)^{2+}$ at pH between 5.0 and 6.0 is the most toxic component for fish, while Al(OH)4- has been correlated with toxicity to algae (Helliwell et al., 1983).

Increased accumulation of mercury and cadmium is observed in acidic lakes (Johansson, 1981). Mercury is found in the form of methyl mercury ions in acid lakes, while mercury in neutral and alkaline lakes is found as dimethyl mercury. The latter has a higher vapor pressure and has therefore a smaller retention time in fresh waters than the methyl mercury ions, which in addition is more easily bioaccumulated in fish.

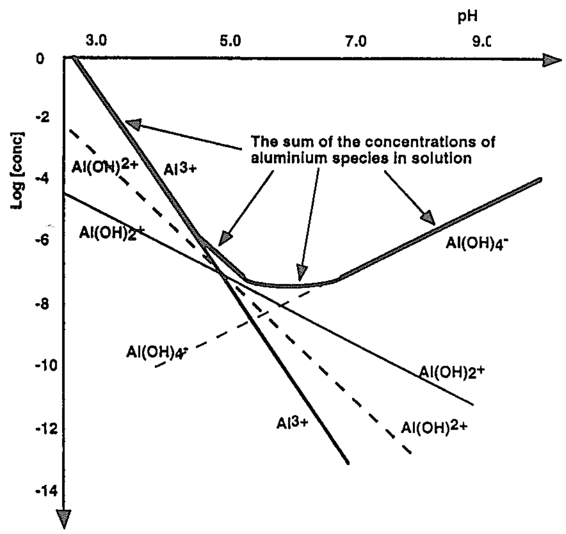

Fig. 2.2 The concentrations of soluble inorganic aluminium species in relation to pH. The sum of the concentrations of aluminium species in solution is shown.

Henriksen and Wright (1978) have examined the concentrations of the series of heavy metal ions (Zn, Pb, Cu, Cd) in Norwegian lakes and found that the acidic lakes generally have higher concentrations. It has not been stated whether the higher concentrations are due to direct deposition or drainage waters.

2.3 OBSERVED EFFECTS ON PRIMARY PRODUCERS

pH increases generally with eutrophication due to uptake of hydrogen carbonate ions by photosynthesis. Long-term reductions of pH may force lakes into an increasingly more oligotrophic state. See Fig. 2.3. The explanation is that either carbon may be removed as carbon dioxide at pH below 5.0 and carbon therefore becomes the limiting nutrient, or that phosphate is reduced due to precipitation by the elevated concentrations of aluminium- and iron ions by lower pH. The allocation of diatoms is found to be highly dependent on pH. Five well-defined groups are used in this relation:

acidobiontic, occurring at pH < 7.0, maximal at pH < 5.5.
acidophilic, occur at pH < 7.0
indifferent, occur equally at circum neutral pH
alkaliphilic, occur at pH > 7.0
alkali biontic occur at pH > 7.0

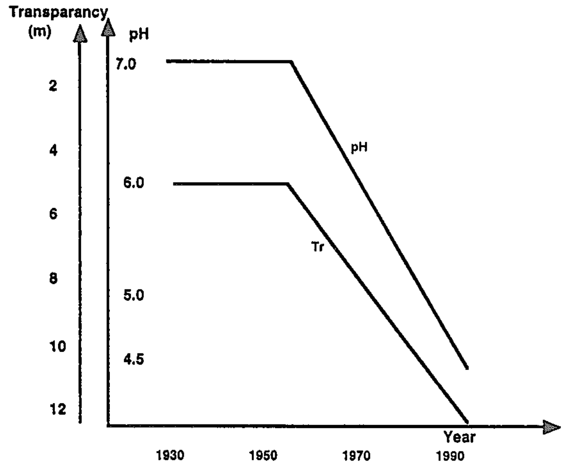

Fig. 2.3 pH and transparency of Lake Sora Skarsjøn in Sweden are plotted versus time. The observed trends in pH and transparency are characteristics for many lakes that have been acidified during the last 2-4 decades.

It is possible to state the approximate pH (by +/- 0.25 units) by determination of the relative occurrence of the five groups. This relationship has been used extensively to reconstruct pH history from sediment core (Howells, 1982).

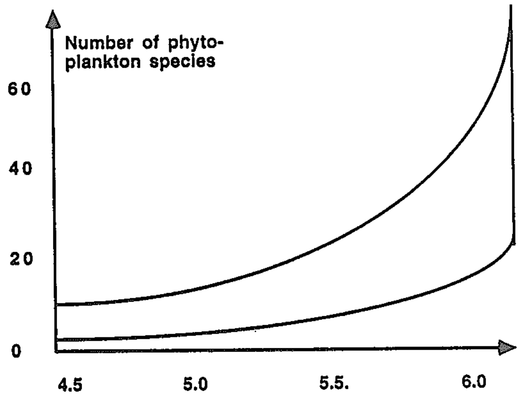

Fig. 2.4 The number of phytoplankton species observed in Swedish lakes versus pH of the lake water according to Johansson and Nyberg (1981).

A decreased pH implies a reduction in the number of phytoplankton species present in the lake. Fewer and fewer species are adapted to the acidity, as pH decreases. Fig. 2.4 shows the number of observed species in Swedish lakes plotted versus pH (Johansson and Nyberg, 1981). There is some evidence that diatoms seem to be favoured by low pH relative to other phytoplankton species. Analysis of the data may reveal that influences other than pH may play a part in determining the survival of diatoms at relatively low pH.

An early manifestation of acidification in Swedish waters was the abundance of underwater *Sphagnum* moss in lakes of pH below 5.0, where it replaced *Lobelia-Isoetes* communities, which is characteristic for oligotrophic lakes at pH above 5.5. This shift in the composition of the macrophyte community reinforces the acidification, as *Sphagnum* generates hydrogen ions by ion exchange with calcium ions. The diversity of macrophytes declines, as does the diversity of phytoplankton, with increased acidity. An examination in the English Lake District has shown, that lakes with some alkalinity have about twice the number of species of acidic lakes (Stokoe, 1983). Several unpublished data indicate that these observations are consistent with what is found in the Scandinavian lakes.

2.4 OBSERVED EFFECTS ON ZOOPLANKTON AND AQUATIC INVERTEBRATES

The differences between acidic and neutral lakes are mostly a replacement of species and a pronounced decrease of the species diversity; see Fig. 2.5. Several studies of *Daphnia* species indicate that cladoceran species are generally sensitive to acute acid conditions. The cladoceran *Bosmina* is characteristic of acidic lakes, replacing the *Daphnia* species neutral waters. Copepods are somewhat less sensitive than cladocerans. They are usually representative of acidic waters (Brett, 1989).

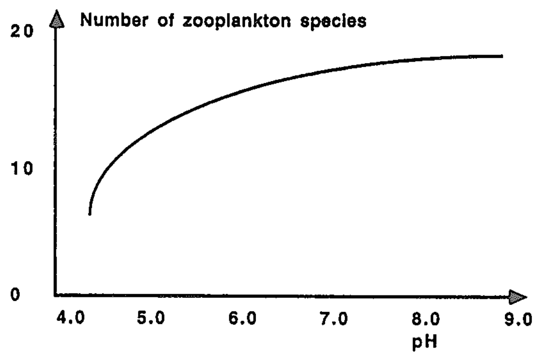

Fig. 2.5 Number of zooplankton species in Swedish Lakes according to pH. The results are from a comprehensive examination of 84 lakes in Sweden.

Effects on zooplankton physiology are reduced filtering, haemoglobin loss, reduced oxygen and sodium uptake and gill tissue damage. The long term effects are reduced brood size and reproductive capacity, and delayed reproduction.

In contrast to fish, invertebrates are usually able to tolerate acid exposure of a day or two. Macro invertebrates are among the most commonly monitored groups of lakes, as they are used as "biotic" indicators of the health of lakes and streams. In lakes with moderate alkalinity and pH above 6.0, the fauna is usually rich in total species and often seasonally abundant. In lakes below 5.6, however, some taxa are absent or scarce. This is particularly noticeable in regard to may-flies, crustaceans and molluscs (Sutcliffe, 1983). The observed distribution of various classes of aquatic species through the range of pH in Swedish lakes is shown in Fig. 2.6. Clearly some species are absent because of a specific deficiency of calcium in low alkalinity streams, such as molluscs, which require calcium for shell formation.

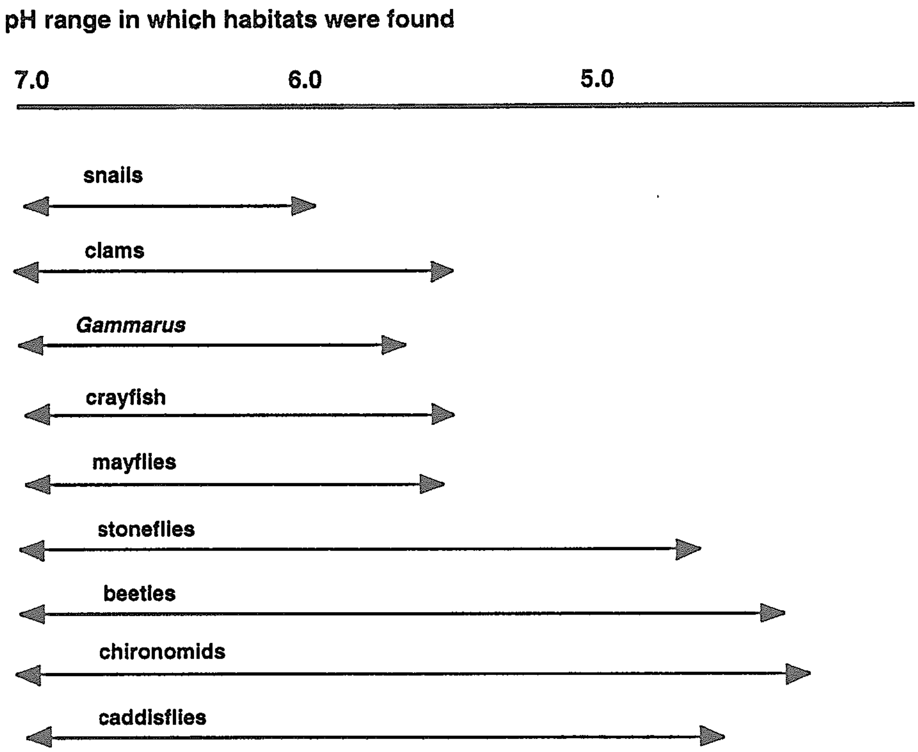

Fig. 2.6 The distribution of various classes of aquatic species versus the pH range.

Some specific investigations show that the following species have very poor survival below pH 5.2: *Gammarus lacustric*, *Gammarus pulex*, *Asellus aquaticus*, and *astacus astacus*; see Okland and Okland (1980), Hargeby and Petersen (1988) and Appelberg (1981).

In contrast, some insect larvae show a wide range of tolerance. It has been found that some insect larvae can survive even at pH 3.5 for long periods. Although some may-fly species are sensitive to acidity, other insect larvae (dragonfly, damsel-fly, caddis fly and stone fly larvae) are typically well represented in acidic waters.

Low acidity affects invertebrates through several toxic mechanisms, such as reduced gas exchange, impaired calcium metabolism, element deficiencies and toxic effects of aluminium ions; see Herrmann (1987).

2.5 OBSERVED EFFECTS ON FISH

Decreasing pH has a striking effect on the fish population, as demonstrated in Tables 2.3 and 2.4. Rainbow trouts are not found at pH < 5.5, chars and lake trouts not below pH 5.0 and brown trouts, pikes and perch are hardly found at pH < 4.5.

At extremely low pH values all young fish disappear completely (Almer et al. 1974). Nevertheless, spawning and fertilized eggs have been observed even at low pH values, so it seems that the development of eggs may be disturbed by high activity of hydrogen ions in the aquatic environment. This is illustrated in Fig. 2.7, where the percentage of hatched eggs is plotted against pH value.

The period from fertilization to hatching also tends to be prolonged at low pH values, as shown in Fig. 2.8. These observations are also in accordance with the trends in occurrence of fish species; see Table 2.5, which clearly shows that it is the reproduction that suffers from the low pH.

Table 2.3 Fish status for 1679 lakes in Southern Norway grouped according to pH

pH	No. of lakes in pH range	% of lakes with no fish	% of lakes with sparse populations	% of lakes with good populations
<4.5	111	73	25	2
4.5-4.7	245	53	41	6
4.7-5.0	375	38	41	21
5.0-5.5	353	25	40	35
5.5-6.0	164	8	36	56
> 6.0	431	1	13	86

As seen from the above mentioned results the relationship between, on the one side, the fish population and, on the other side, the pH is not completely unambiguous. Chester (1986) suggests, that the effect on the fish population is indirect. Chester mentions the positive influence of the calcium ion concentration on the fish populations, as calcium ion concentration has a strong influence on the LC-50-value of ammonia for fish. Another important indirect effect is due to the lower complexation of heavy metals by low pH, causing a higher uptake of toxic heavy metal ions by fish. This is shown for mercury in Fig. 2.9.

Table 2.4 Trout population and pH in 260 Norwegian lakes*)

No. of lakes Population	pH 4.00-4.50 No.	%	4.51-5.00 No.	%	5.01-5.50 No.	%	≥ 5.51 No.	%
33 Empty	3	9.1	17	51.5	7	21.2	6	18.2
87 Sparse population	2	2.3	15	17.2	21.2	24.1	49	56.3
82 Good population	-	-	9	11	14	17.1	59	72
58 Over-populated	-	-	3	5.2	13	22.4	42	72.3
260 total	5	1.9	44	16.9	55	21.2	156	60

*) Results are based on an examination carried out by Jensen and Snevik (1972).

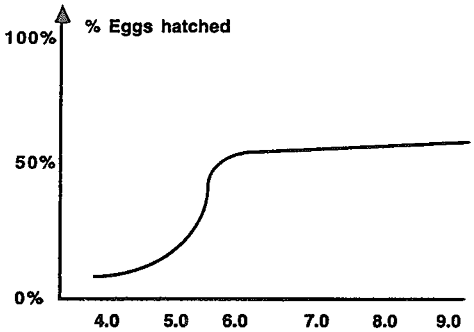

Fig. 2.7 % eggs hatched according to pH. Total number of eggs reared 253-274.

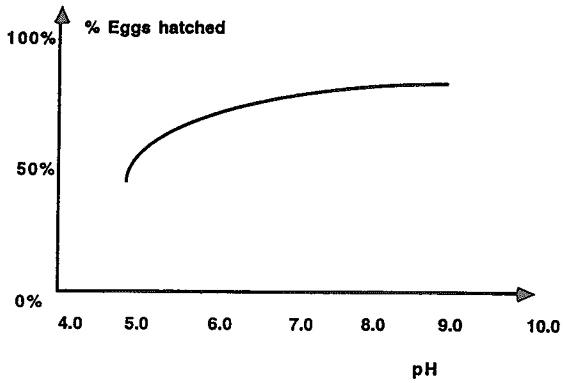

Fig. 2.8 Eggs hatched during the first 96h after fertilization as percentage of total number of hatched eggs according to pH; see Fig. 2.7.

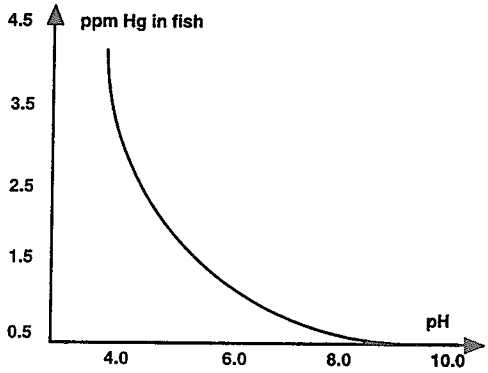

Fig. 2.9 Effect of pH on the mercury content of fish. Exposure to 1.5 ppm Hg from $HgCl_2$ solutions.

Table 2.5 Occurrence of fish species before acidification and species found during 1973 in some Swedish lakes

Lake	Earlier species forming permanent stocks	Species found 1973	Species re-producing 1973
Bredvatten	Pe Pi E	(E)	
Lysevatten	Pe Pi R E	Pe (E)	Pe
Gårdsjön	Pe Pi R T C E	Pe Pi E	Pe
Örvattnet	Pe St M	Pe	Pe
Stensjön	Pe Pi R St M	Pe Pi R	Pe Pi
Skitjärn	Pe Pi R L	Pe Pi R L	Pe Pi

Pe=perch (*Perca fluviatilis*), Pi=pike (*Esox lucius*), E=eel (*Anguilla vulgaris*), R=roach (*Leuciscus rutilus*), T=tench (*Tinca tinca*), C=Crucian carp (*Carassius carassius*), St=Brown trout (*Salmo trutta*), L=Lake whitefish (*Coregonus albula*), M=Minnow (*Phoxinus phoxinus*).

A characteristic of damaged fish populations in acidified lakes is, however, not just the absence of fish, but that the structure of the population is anomalous. In a healthy population, numbers in their first year are such that the recruitment class is usually high; most natural loss occurs during this early stage. In the following year, survival is generally good and each year class prior to migration or spawning will be represented in the population. In acidic lakes, in contrast, annual classes are sometimes entirely absent, or grossly depleted; see also Table 2.5. Often a few older and larger fish are found, possibly the remnants of populations present before the acidification.

Acidity is clearly a crucial factor in determination of fish populations and fishery in lakes. Table 2.6 summarizes the observations of pH on fish populations (Alabaster and Lloyd, 1980). However, it is clear from the discussion in this section and the previous sections that there are several factors, including indirect effects, to account for simultaneously which makes the entire problem very complex. It may nevertheless be concluded that a low pH has a pronounced negative effect on fish populations due at least to a reduced hatching efficiency and due to a higher uptake by the fish of heavy metals.

Table 2.6 Effects of pH values on fish (Alabaster and Lloyd, 1980)

pH-range	Effect
3.0 - 3.5	Unlikely that any fish can survive more than a few hours
3.5 - 4.0	Lethal to salmonoids. Some other fish species might survive in this range, presumably after a period of acclimation to slightly higher pH
4.0 - 4.5	Harmful to salmonoids, bream, goldfish and carp, although the resistance to this pH increases with the size and age
4.5 - 5.0	Likely to be harmful to eggs and fry of salmonoids. Harmful also to adult salmonoids and carp at low calcium, sodium and/or chloride concentration
5.0 - 6.0	Unlikely to be harmful, unless concentration of free CO_2 is greater than 20 mg l^{-1} or the water contains freshly precipitated $Fe(OH)_3$
6.0 - 6.5	Harmless unless concentration of free CO_2 > 100 mg l^{-1}

2.6 OBSERVED EFFECTS ON AMPHIBIAN AND RIPARIAN FAUNA

Different species of amphibians exhibit a wide range of sensitivity to acidic water. Experimental studies have demonstrated response to acidity and particularly to the associated high aluminium levels. The common toad, *Bufo bufo*, showed some mortality in the presence of aluminium at pH 4.5 or lower. Similar results were obtained for three species of frogs with a lethal pH level at about 3.5.

Effects are particularly seen at the egg hatching stage, while the larvae become progressively more tolerant and the adults of these species are found in waters of a wide range of acidity up to even pH 3.0.

Two species of salamander, *Ambystoma* spp., showed reduced breeding success in acidic waters.

The question of ecological significance of inability to hatch amphibian species is strongly related to the pronounced seasonal nature of egg production during the spring snow-melt period, which means that hazards are high under all circumstances. However, embryos that hatch and develop to the tadpole stage are evidently resistant to acid conditions, although still highly susceptible to predators.

Riparian birds have been identified to be at risk from acidification, either directly or indirectly through other biological changes. Some species, such as dippers, are totally dependent on the adjacent aquatic ecosystem as a food source. It has been shown that dippers decline in numbers parallel to an increase in acidity in a group of streams over the past 30 years (Ormerod, 1985). In contrast, the grey wag-tail does not show this relationship, because it does not feed on aquatic insects. This led to the hypothesis that aluminium residues in the prey organisms were the cause for the reduced number (Nyholm, 1981). However, this has not been supported by analytical evidence (Otto and Svenson, 1983).

Lack of fish seems a more plausible explanation for the absence or scarcity of fish-eating birds than the aluminium concentration in fish. The reaction of some duck species illustrates the complexity of the problem. They have shown to benefit from low pH, probably due to the reduced competition from fish in acid lakes.

Two main factors can explain the reduced bird population at the shore line of acidic lakes: the increased concentration of toxic metal ions in the water and the reduced numbers of fish.

Concern has also been expressed regarding the effect of acidification on mammals, particularly otters. The depletion of otters seems, however, more related to the loss of habitat than to any other factors.

2.7 OBSERVED EFFECTS ON THE LAKE ECOSYSTEM

Lakes play a significant role as a buffer on physical, chemical and biological factors in the entire catchment area.

Acidification of lakes implies a pronounced reduction in the biodiversity of the lake ecosystem. Numerous investigations have revealed a relationship between the pH of lake water and the diversity index; see for instance Likens et al. (1977) and Okland and Okland (1980).

It can be concluded that lake ecosystems become poorer in dynamics as well as in diversity - in quality as well as in quantity. It is, therefore, understandable that acidification is considered one of the most serious pollution problems in the Scandinavian countries, where acidification is a threat to aquatic ecosystems.

Another clear effect of acidification is a significantly slower turn over rate due to reduced rates of practically all biological processes. The effect is pronounced as can be seen in Figs. 2.10 and 2.11.

Experimental studies in some Scandinavian lakes indicate that glucose utilization was reduced at low pH. A marked seasonal and year-by-year variation in glucose cycling was found in Swedish lakes. Field studies have shown that respiration was reduced to about 10% of that at pH 7.2. All in all slower turn over rates of carbon, nitrogen and phosphorus should be expected as a consequence of lower pH. As the ability of the ecosystem to resist changes - the ecological buffer capacity - is correlated to the flow rates, ecosystems will be expected to be more vulnerable at lower pH (Jørgensen, 1994).

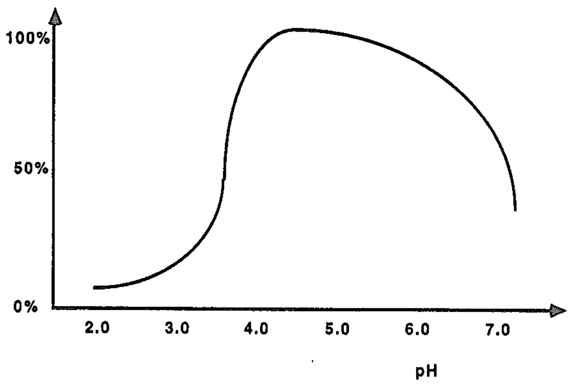

Fig. 2.10 The relative decomposition rate of cellulose plotted versus pH. The maximum decomposition rate is the pH range of 5.0 -6.0.

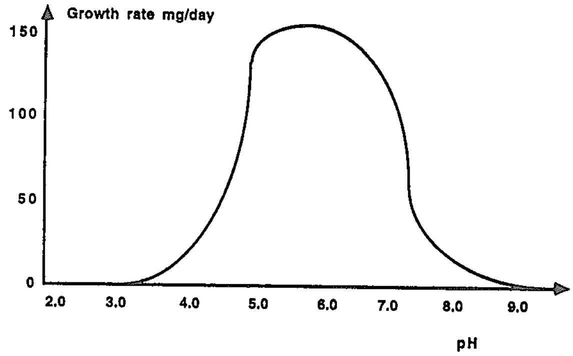

Fig. 2.11 Growth of a fungus, *Merasmius graminum*, as a function of pH.

2.8 SUMMARY AND CONCLUDING REMARKS

Scandinavia suffers from acidification of lakes due to low pH- buffer capacity of the lake water and due to the emission of acidic gases mainly from the most heavily industrialized regions of Europe. Several thousands of beautiful lakes in this most untouched nature of Europe show a wide spectrum of adverse effects due to pH values below 5.0. The most pronounced observed effects can be summarized in the following points:

1. Low or no alkalinity of lake water. Change of anion composition from hydrogen carbonate to sulphate;

2. Reduced biodiversity of all species;

3. Elevated concentrations of heavy metals in lake water and biota; and

4. Slower turn over rates, causing reduced ecological buffer capacities.

As seen from this list of adverse effects which is in no way exhausting, the effects of acid rain change entirely the ecosystems to biologically poor and more vulnerable ecosystems which from an environmental point of view is completely unacceptable. Measures have been taken to reduce the emission of acidic gases, but all models of acidified lakes show that a further reduction is absolutely necessary to change the direction of the adverse effects for most of the lakes. Liming is used widely in Scandinavian countries to reduce the effects (see the Guidelines of Lake Management, Volume 5, Management of Lake Acidification), but it is costly. If lake acidification continues inexorably and include also the larger lakes which have been spared up to now due to their long water retention time, the application of liming will be prohibitively expensive. In other words, there is only one solution to the problem: reduced emission of acidic gases.

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CHAPTER 3

MAIN PROBLEMS FACING ENDANGERED CHINESE LAKES WITH SOME SUGGESTED PRINCIPLES FOR THEIR RESTORATION AND SOME EXAMPLES

Yan Jingsong & Zhang Yushu

3.1 A BRIEF ACCOUNT OF CHINESE LAKES

China is rich in lakes. According to our statistics, although some natural Chinese lakes vanished and most of the others have reduced their areas and volumes to a greater or lesser extent during the last three decennia, there are about 24,000 natural lakes including 107 big lakes, each with an area of more than 100 km^2, 450 middle-sized lakes with areas between 10 and 100 km^2, 1,577 little lakes with areas between 1 to 10 km^2 and many very small lakes with areas of less than 1 km^2 (Table 3.1). Besides temporary lakes, the total water storage of lakes with areas of more than 1 km^2 is about 7,088 billion m^3 including 2,600.5 billion m^3 of fresh water, based on the mean annual water level of each of these lakes. In addition to natural lakes, about 86,000 artificial lakes (reservoirs) with 4,100 billions m^3 of total storage capacity have been built in China. Although the total area of lakes occupies a small fraction (only about 0.8%) of Chinese territory, they are of great importance to the environmental system and to natural resources, and provide many services and commodities to people. For example these lakes abound with a great amount of diverse resources such as water, water power, aquatic life and products, flats with many species of hydrophyte and mesocole, minerals, landscapes, microclimates etc.. Most Chinese lakes are used by humans for many purposes including fishing, transportation, irrigation, industrial water supplies, hydroelectric development, receiving and self-purification of wastewater effluent and improving water quality, and making recreational attractions by using the lake's aesthetic and heritage value. Besides their importance for human use, these lakes have intrinsic ecological and environmental values. They store water, thereby helping to regulate the runoff volume and dredge of floodwater and moderate the effects of floods, water logging and drought resistance, and recharge ground water aquifers. Lakes provide habitats for aquatic and semiaquatic plants and animals which in turn provide food for many terrestrial animals, thereby preserving and adding to the diversity of the landscape. They moderate temperature and affect the microclimate of the surroundings. They also contribute to the regeneration cycle of materials, such as nitrogen, phosphorus, carbon, sulphur, etc., and their stability at regional and even global levels.

Table 3.1 The number and area of Chinese lakes with each area more than 1 km^2

	Type	Number	Area (km^2)
Big (>100 km^2)	outflow	69	22180.6
	inflow	43	27809.0
	temporal	7	6132.0
	total	107	56121.6
Middle (between 10 - 100km^2)	outflow	162	5146.9
	inflow	255	9261.9
	temporal	33	1104.2
	total	450	15513.0
Little (between 1.0 - 10.0km^2)-	outflow	827	2506.4
	inflow	405	2553.5
	temporal	345	1002.8
	total	1577	6062.7
Total	2134	77697.3	

3.2 SOCIAL-ECONOMIC-NATURAL COMPLEX LAKE ECOSYSTEMS (SENCLE)

3.2.1 Meaning: This is the basis and first step for solving the problems facing endangered lakes and, for reasonable and sustainable use as well as conservation of lakes, for recognizing the characteristics of modern lakes. As we know, lakes were originally one of the natural ecosystems. Recently, most lakes differ from the traditional natural lake ecosystem in that they are more or less acted on and affected by human activities. The major problems facing endangered lakes, such as hydrologic and related physical changes; eutrophication; degradation of water quality; reduction or loss of some original ecological, economic or social functions; destruction of some lake ecosystems, etc., are complex ones which are all concerned directly or indirectly with social and economic conditions, and the natural ecological environment on which humans rely. Although the social, economic and natural systems are different in their characters, having their own structures and developmental rules, the existence and development of each of them are conditioned by the structures and functions of the others, so it is obvious that the above complex problems are not only a natural one, nor solely economic or social ones separately, but are problems of the social-economic-natural complex. Most modern lakes are Social-Economic-Natural Complex Lakes Ecosystems (SENCLEs), belonging to a social-economic-natural complex ecosystem (Ma & Wang, 1984).

3.2.2 Structure and Functions of SENCLEs

A SENCLE may be considered as an organic entity or system integratively composed of three layers (subsystems) with crisscross relationships among them (Fig. 3.1). The core is human beings, including the organization, technology, and culture, comprising laws, strategies, customs and traditions for management and utilization of lakes. This is the controlling part of SENCLEs, and may be called the Eco-core. The second layer is the direct environment of human activities within a SENCLE, including the geographic, biological and artificial environment, which is the fundamental medium for human activities and is called the Eco-base. The third layer is the external environment of SENCLEs, including source, store, and sink, which is the external supporting system of SENCLEs and called the Eco-pool (Liu et al., 1986; Ma & Wang, 1989). These three layers are interacting upon one other. There are two borders in SENCLEs which are different from that of the traditional natural ecosystem. The inner border, i.e. the border of the eco-base, has a specific spatial location, but the area it encloses is not a complete functional entity, because it belongs to the open system which exchanges substances, energy and information with the surroundings, and belongs to a dissipative structure far from the state of thermodynamic equilibrium which may generate negative entropy and make an interruption or eddy in the straight-line progression towards entropy, with diversion routes away from the eutrophic ends of life. It is a necessary condition for existence and development of a dissipative structure that negative entropy is generated by energy and material transfer. The coincident effect of energy dissipation is the internal force for ecosystems to produce ordered structures, and the entropy generation of the coincident effect is negative. Therefore it depends on support from the external environment for most of its materials, energy, information, capital and people flows. While the outer border has no specific location, it only represents the scope of effects from those sources, sinks and stores which are related to the inner eco-base. Its functions may be represented by an octahedron in Fig. 3.2. The vertices H (Human being), P (production), L (living), R (resources), E (environment) and N (nature) represent the control, production, living, supply, acceptance and reduction/regeneration functions respectively. They can be classified into three groups:

```
                      ┌──────────── control
Social functions ─────┼──────────── production ──┐
                      └──────────── living        │
                                                  │
Natural               ┌──────────── supply ───────┼──────── Economic functions Natural
functions ────────────┼──────────── acceptance ───┘
                      └──────────── reduction
```

These three kinds of function depend on each other and comprise the complicated SENCLE relationships: the relationships of promotion, restraint, adaptation, and reformation between man and nature; human resources relationships through the action of exploitation, utilization, processing, and storing resources, and human relationships of competition, symbiosis, enslavement and submission in living and production activities. The succession of a SENCLE is the result of interaction of natural succession and human exploitation. There are two kinds of effective factor: one is the leading factor; the other is the limiting factor. When the leading factor prevails, various human activities lose no time in making use of the favourable ecological niche and the system grows in an almost exponential way. At this time, the main goal is to gain high speed and efficiency, and the process is characterized by competition behaviour, struggling for the leading factors. With the rapid occupation of an ecological niche, some scarce ecological factors gradually turn into limiting ones, thus the growth speed is hindered and the process becomes a threshold type. At this time, the main goal is to maintain the stability of the development, and the process is characterized by symbiosis behaviour compromising with the limiting factors. However, a SENCLE has the tendency of transforming its environment and breaking the restriction of a limiting factor actively, through changing the dominant species, alteration of the inner structure, improving the environmental conditions and so on. Thus the carrying and buffering capacities are enlarged. The old limiting factors will therefore become leading factors and new limiting factors will emerge (Ma & Wang 1989).

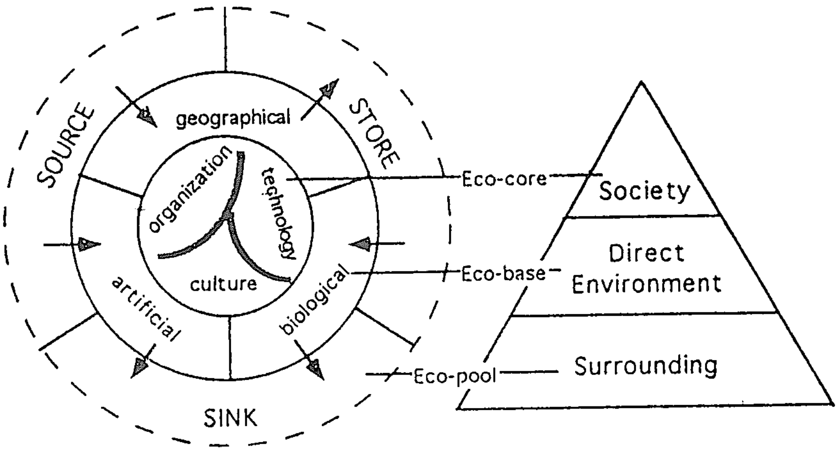

Fig. 3.1 The structure of the Social - Economic - Natural Complex Ecosystem (SENCLE), a system that describes the overall goal of ecological engineering in China (after Ma and Wang, 1989).

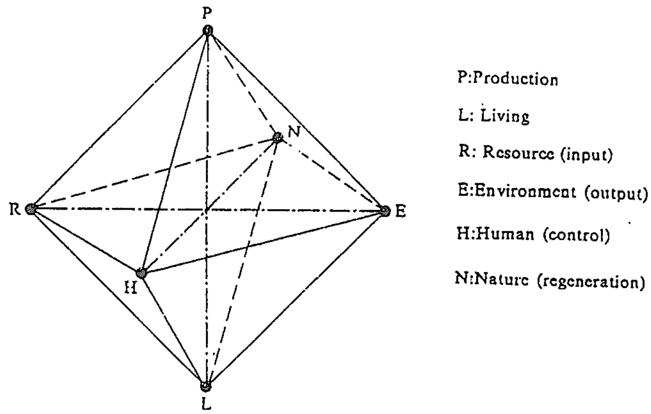

Fig. 3.2 The function of SENCLE.

3.3 GENERAL PROBLEMS FACING ENDANGERED CHINESE LAKES

Many surveys and assessments of conditions in Chinese lakes have been made. Based on these results, including our researches, the general problems facing endangered Chinese lakes are summarized as follows:

3.3.1 Hydrologic and Related Physical Changes: In the early 1950s, China had a total of about 24,800 natural lakes and 83,400 km^2 of lake areas including 80,645 km^2 of lake areas and more than 7,658 billions m^3 of water storage in 2,848 lakes with areas of more than 1 km^2. In only 30 years from the 1950s to the 1980s, 543 big and middle-sized natural lakes and many little ones with areas of less than 1 km^2 had vanished, and most of the others had decreased in their areas and depths to a greater or lesser extent. 11,585 km^2 of total lake area and more than 570 billions m^3 of regulating storage, including 8,858 km^2 of water area and more than 568 billions m^3 of storage of big and middle-sized lakes, were lost. Among these the most seriously destroyed regions are in the catchment of the middle reaches of Changjiang River and the arid and semiarid areas in North-west China.

The main causal stresses on the decrease of the areas of Chinese lakes and water storage, and the disappearance of some lakes, are mainly the imbalance of the water and/or silt budget and excessive reclamation.

3.3.1.1 Water Imbalance in Lakes

The imbalance of water budget in lakes. This is common in the arid and semiarid regions in the Qinghai-Tibet Plateau and the Mongolia-xinjiang Plateau where the mean annual precipitation is below 250 mm/a in arid regions and 250-400 m/a in semiarid regions. The water imbalance in a lake is aggravated by over-use of the surface water or of groundwater in the lake's water sources, thus decreasing inflow into the lake; and/or an over-increase in the outflow from a lake, which causes the water output to be greater than water input, resulting in drawdown of the water level and decrease of lake areas and storage. For example, in Lake Qinghaihu, the largest inland lake in China, 383 km^2 of water areas and 308 billion m^3 of storage were lost in the last 20 years (from 4,583 km^2 and 1,050 billions m^3 in 1957 to 4,200 km^2 and 742 billions m^3 in 1981) because, mainly, the inflow into the lake was decreased. The water imbalance in the lake was aggravated by the great increase in the scale and amount of irrigation for grassland and agricultural fields in the catchment of this lake. In Caidamu Basin, Qinghai Plateau, the water area of Dulan lake decreased to 20.8 km^2 in 1972 from 34.6 km^2 in 1958, and Caikia lake had dried and become a part of a desert, because many water diversion works were built in their upstream region. In Sinkiang Uighur Autonomous Region, there were 9,700 km^2 of water area in 52 middle lakes with areas of more than 5 km^2 in 1950s, but 2,628 km^2 of them were lost from the 1950s to the 1980s. Lakes Luobupo, and Taitema, with original water areas of 3,006 km^2 and 88 km^2, had dried up since 1964 and 1972 respectively, because of the agricultural reclamation and many water conversion works in their catchment and upstream area, developed since 1957.

Another typical example is that of Lake Erhai situated in Yunnan-kweichow Plateau. In 1972 a hydroelectric station, which used about 7 billion m^3 of water discharge per year from the lake, was built in its outlet stream. The great increase in the amount of discharge from the lake resulted in 2.73 m of water level drawdown, and 3.64% of the water area and 23.8% of the storage had been reduced by 1982 compared to the mean annual lowest statistical data from 1951 to 1971. These changes had caused a series of chain reactions. For example the drawdown of the lake's water level increased the gradient of the inlet streams, drew down the erosion basis in the inlet streams, and aggravated the scouring on the inlet streams by the inflow, especially in floods. This change resulted in more than 15 km of inlet stream being scoured and the river bed being cut down; many piers of some bridges in this inlet stream sank. This also increased the difficulty of drawing water from the lake to the farmlands, and caused a sharp fall in groundwater level in the area near the lake. Therefore, 1,093 wells changed, including 502 wells which dried up, 479 wells that became semi-dried, and 112 that were polluted. Drawing water from the wells for living therefore became difficult, which affected 91,000 people and 16,000 livestock in the lake's surroundings. The decrease of water storage in this lake reduced its heat storage and its effect in regulating the microclimate. Since 1982, the frostless season in the surroundings of Lake Erhai has reduced by 9.5 days and the weather became abnormal compared to that in the period from 1971 to 1982. These changes affected also the community composition and their habitats in this lake. The original littoral area and most of the sub-littoral area became dry, where it was originally abundant with aquatic vegetation. For example *Potamogeton pectinatus*, and *Najas major* vanished or were decreased. Most of the original profunda area became shallow in water depth, and was colonised by many species of submerged plants, such as, *Potamogeton nacthanus*, *Hydrilla varticillata*, *Ceratophyllum denersum*, etc.. The total area of submerged vegetation enlarged to 2/3 of the area of whole lake, which promoted the lake becoming swampy but favoured the growth and fertility of some herbivorous fish and those fish which spawn in aquatic plants, such as crucian carp and common carp. These became the dominant species of fishstock and their annual output has increased to 80-100 tons since 1982. Meanwhile the original dominant native species of fish, such as *Schizopyge takiensis*, which needs to migrate to the inlet streams of the lake for spawning and laying its eggs on the gravelly bed of the river, and *Puntius exigua*, which spawns in the gravelly beaches in the littoral area of the lake, decreased more and more and tended to extinction, because their original optimal spawning ground was destroyed by the drawdown of the water level.

3.3.1.2 Silt Imbalance in Lakes

Another of the main causal stresses on the reduction of lake water area and storage in Chinese lakes occurs when the input of silt is more than the output silt discharge of a lake. A great amount of siltation has occurred in some Chinese lakes because of the inadequate erosion control in agricultural, forestry and mining activities. This problem is common in those lakes situated in the catchment of the middle reaches of the Changjiang River. The mean annual silt discharge at Yichang Section at the beginning point of the middle reaches of Changjiang River was about 5.7 billion tons, and most of this was discharged to and deposited in some lakes in the river drainage area. For example, the mean annual input and output of silt discharge to and from Lake Dongtinhu were 207,550,000 and 55,000,000 tons, and their mean annual sedimentation rate and accumulation were 3.7 cm and 152,250,000 tons respectively. This resulted in the sediment depth on the lake bed being raised 2 m in mean and 8 m at its highest in its east region, 2 m (mean) 6 m (highest) in its south region, and 4.5 m (mean) and 8 m (highest) in its west region. The sedimentation not only resulted directly in reduction of water areas and storage, and raised the lake bed and water level, but also promoted the development of lake beaches including flat shoals, sand bars, fresh meadows and deltas. The expanding mean annual area of lake beach was about 40 km^2 in the lake. The rapid development of the lake beaches provided a natural condition favouring reclamation from the lake which will further decrease the water area and storage in a lake (Sun, 1983). The mean annual silt discharge input to, output from, and siltation in Lake Poyanghu were 21.085, 10.406 and 10.679 million tons respectively during 1952 to 1984. The deposition area was mainly distributed in the inlets of five inlet streams of the lake where the lake surface suddenly enlarges and the flow rate drops down quickly, so that deltas were formed and expanded. After the deltas increased to a certain height, they were usually reacclimated and enclosed by reclamation dams. Then, the height of the lake bed outside the reclamation dam came to increase continually by new siltation, which resulted in the area outside the reclamation dam becoming higher than that inside the dam, so that the new, expanding part outside the old dam were reclaimed and enclosed by new reclamation dams. This was repeated time and again. The enlarged and expanded delta and reclamation district made the inlets of these rivers stretch continually towards the centre of the lake. For example, the inlets of the West, Middle, South and North Branches of Ganjiang River had stretched 7, 7, 12, and 11 km respectively from their original positions towards the centre of lake from 1949 to 1984. The mean annual sedimentation rate was 25 mm in the region near the inlet of Ganjiang River, and 69 mm in the region near the inlet of Fuhe River. The sedimentation formed a "natural dam and with bird's toe stretched to the downstream in the lake along two sides of the principle channel in the lake" (Zhang, 1989).

3.3.1.3 Excessive Reclamation from Lake

Reclamation from lakes is one of the main artificial conditions aggravating the reduction of water areas and storage of lakes. During the 1950s to the 1980s, in order to solve the problem of food insufficiency in China, and putting undue emphasis on the strategy of "Grain production must be taken as the key link in agriculture", a total of more than 13,000 km^2 of area were reclaimed from lakes in the whole country. This aggravated the reduction of water area and storage of many Chinese lakes. For example, 1933.3 km^2 of area were reclaimed in Lake Dongtinhu from 1949 to 1985. This added to sedimentation and resulted in 1,659 km^2 of water area and 94 billion m^3 of storage reduction: 4,350 km^2 and 268 billion m^3 in 1949 decreased to 20,091 km^2 and 174 billion m^3 in 1985. This occupied 38.1% of the water area and 35.1% of the storage of this lake in 1949. In Jianghan Plane close by and relative to the middle Reaches of Changjiang River, there were 1,052 lakes with 13,000 km^2 of lake area, including 4,707.5 km^2 in 609 lakes with areas greater than 0. 5 km^2 at the end of the 1950s. A total of more than 6,000 km^2 of area were reclaimed in these lakes from the 1950s to the early years of the 1980s. Among them, about 300 lakes completely vanished and the water areas of the middle and big lakes were decreased by 2,051 km^2. In Poyanghu Lake 1,212.3 km^2 of lake area were reclaimed from 1949 to the 1970s, 10,679,000 tons of mean annual sedimentation resulted in 1,168 km^2 of water area and 75 billion m^3 of storage, occupying 26.6% of its original water area (4,390 km^2 in 1954) and 23.3% of its original storage (336 billion m^3 in 1954) being lost. In the drainage basin of Lake Taihu, 33.8% (239 of the original number of 708 lakes) in this region were reclaimed from 1949 to 1985. Among them, 165 lakes, with their 161 km^2 of water areas, completely vanished. In the catchment of Huanhe River a total of 1,125.13 km^2 of area was reclaimed in six large and middle lakes, besides the reclamation from many little lakes in this region.

Reclamation from lakes not only directly reduces their areas and storage, but also causes a series of environmental changes and impacts on many social, economic and natural functions.

The main transient beneficial results from reclamation in lakes are that:

More than 13,000 km^2 of land, including about 10,000 km^2 of farmland, were gained by reclamation from lakes in China, which greatly increased crop production. Some reclamation districts where there are still waterlogged depressions are usually used as controllable intensive fish culture ponds, increasing output of aquatic products. In addition, reclamation can destroy the habitats of *Oncomelania hupensis*, a kind of freshwater snail which is the intermediate host of blood flux, so that reclamation from some lakes can favour elimination by *Oncomelania* and prevent schistosomiasis. For example, 60,000 ha of grass swamp and reed marsh, the breeding ground of *Oncomelania* in Poyanghu Lake, was reclaimed, which resulted in 65.2% of the total area of the breeding ground of this intermediate host of blood flux being eliminated, reducing by 2/3 the scope of the schistosomiasis infectious area in this region and reducing considerably the incidence of schistosomiasis in the region of Poyanghu Lake. However, besides the transient beneficial results from reclamation mentioned above, a series of damages are brought by reclamation from lakes.

Control of changes of morphology of the lake basin and increase of load for flood and water logged farmland control

Lake beaches are usually situated in the upper part of a lake and commonly the high siltation area. This forms flat shoals with a low (about 0.1%) slope. After these are reclaimed, the flood cannot overflow and siltation stops in the reclamation districts, because the reclamation dam or coffer dam severs their connections with the open water of the lake, and/or that of the streams and rivers with the lake. The lake beaches and beds outside a coffer dam or reclamation dam are continually and gradually raised by siltation with the passing of time. Therefore, because the height of the surroundings outside the reclamation district is higher than the dams, the efficiency of the sluiceways and sluice gates of the water conservancy facility for draining flood water and for waterlog control in the reclamation district and downstream of the lake is reduced or even lost. This problem is common and obvious in Lake Taihu, Poyanghu, Dongtinhu and Hongtzehu. For example, in Lake Hongtzehu the height of fields in 42% of the area of six reclamation districts built in the 1950s, 54.9% of the area of 25 reclamation districts build in the 1960s, and 67.9% of 34 reclamation districts built in the 1970s has come under the regulated water leaving this lake. Therefore most of these reclamation districts are frequently in flood and waterlogged, and increase the load for flood and waterlogging control.

Upsetting the original schema of the water system and changing the hydrological regime of some lakes

Many Chinese lakes connected with rivers, streams, other lakes and ponds in their drainage basin, form a "water net" region with a complex hydrological regime, which gives many benefits of water conservancy for regulating flood discharge, water level, and waterlogging control.

Reclamation from lakes not only decreased the regulation capability or storage of many lakes, but also raised the water level and changed the hydrological regime in some regional sectors, because the reclamation dams and districts narrowed or blocked the water passages of inflow and outflow rivers of the lake, thus upsetting the original schema of the water system and changing the hydrological regime in some regional sectors. For example, reclamation resulted in the area of East Lake Taihu, which was originally the principal passage and area of flood discharge, reducing its area to 163 km^2 in the 1980s from 265 km^2 in 1916; the width of one of its main discharge sections near Yaojiachuang Village, narrowed to 0.2 km in the 1980s from 6 km in 1916; from 84 outflow rivers in the early years of the 1950s, streams and ditches decreased to >10 in the 1980s; the mean and maximum discharge at Guohjinkou, one of the main outlets in Lake Taihu, reduced to 13.7 and 89.9 m^3/sec in the 1980s from 25.5 and 172 m^3/sec in the 1950s. Another example is that the number of inlet streams from Yuanjiang River to Lake Dongtinhu was 10 in 1958, but only one of them remained in 1974, mainly due to reclamation. Based on calculation and estimation, the water level at Chenglinji, in the main outlet of Dongtinhu Lake, should have risen by 30 cm when 1000 km^2 of lake area were reclaimed. However the water level has risen 49 cm since 1949. In 1980, in Lake Dongtinhu, the maximal total discharge from all inflow rivers reached 74,063 m^3 /sec, which was similar to the median water level in past years, but the water level of the flood peak in this year was higher than that in historically similar years, attaining the third highest flood water level since 1949, and exceeding the warning water level. The period of its flood retention lengthened to 46 days. This abnormally high peak flood water level occurred in a year of median water level mainly due to reclamation from lake.

Accelerating Sediment Rate and Rising Lake Bed Result in More Difficult Navigation through Lakes

Because the lake area was reduced by reclamation from the lake, the sedimentation rate and rate of rising of the lake bed were faster for the same sediment discharge as in the past. This resulted in most of the navigated lanes in the lake being swallowed up and being too narrow for navigation. For example, the length of all usable navigated lanes in Lake Poyanghu reduced to 400 km in the 1980s from 1,359 km in 1953, because the lake bed rose due to reclamation. As a result most of the freight transport had to trans-ship by land, which greatly increased transport expenses and lengthened the turnover time of freight transport, hampering the growth and development of the economy in this region.

3.3.2 Destruction and Loss of Most of the Littoral Zones and Meadows in Lakes

Again, reclamation from lakes injured usually valuable littoral zones and meadows. Most of the littoral areas in many Chinese lakes have been reclaimed for terrestrial agriculture and the construction of towns, villages, fish ponds and highways. For example, from the 1950s to the 1980s, about 5,700, 3,600 and 1,936 ha of littoral zone were lost in Lakes Taihu, Gehu, and Taohu, occupying 80%, 90%, and 97% of their original littoral areas respectively. About 5,000 ha of meadows, occupying 30% of their original areas in 1954, were reclaimed in Poyanghu Lake. This resulted in a series of negative impacts on the environment, fishery, animal husbandry and recreation in these lakes.

Reduction or Loss of Swamping and Feeding Ground of Fishes

Most littoral zones and meadows are abundant in hydrophytes, emergent and submergent vegetation in lakes, and are the optimal spawning grounds for some fish, such as common carp and crucian carp, which lay sticky eggs attached to some aquatic macrophytes. They are also feeding grounds which not only provide much eatable grass for herbivorous fish and water fowl, but also provide habitats for the proliferation and growth of many invertebrates, such as snails, shrimps, aquatic earthworms and insects, which in turn provide food for some carnivorous fish. Destruction and loss of the littoral zone and meadows in some lakes destroys or reduces the spawning and feeding grounds of fish, thus decreasing their production and changing the composition of some fish stocks. For example, the spawning ground of common carp and crucian carp in Lake Poyanghu reduced to 14 sites and less than 10,000 ha in the 1980s, from 55 sites and 25,000 ha., thus greatly decreasing the production of fishery in this lake. The predominant species of fish stock in Lake Taihu have been replaced by some species of ice fish (*Neosalax oligodontis, N. tangkahkeii taihuensis*) and the anchovy (*Coilia brachygnathus, C. ectenes Taihuensis*) which inhabit open water, due to the loss of the littoral zone in this lake. Loss or reduction of littoral zones and meadows in some lakes has an impact on waterbirds because the habitat, including the feeding and spawning grounds of many waterbirds and the overwintering grounds of some migratory birds, including some endangered species, have been destroyed or lost. For example, the waterbirds in Honghu Lake had decreased to 39 species, belonging to 9 families, and 8 orders, in the 1980s from 51 species belonging to 18 families and 9 orders in the1960s; the predominant species has changed from the wild goose (*Anser indicus, A. Anser, A. fabatis and A. cygnodies)* in the 1960s to *Fulica atra* and *Capella gallinago* in the 1980s; the mean annual amount of hunted waterbirds reduced to 13,000 tons in 1979-1980 from 33,000 tons in 1958-1960. Many middle-sized lakes in the catchment of Taihu Lake and in the northern region of Jiangsu Province had an abundance of wild ducks and ducklike swimmers, because they were the overwintering grounds of these birds. The bag of these wild ducks was one of the native products and a source of economic income for local people. But, after the littoral zones and meadows were reduced and lost in these lakes, the number and species of wild ducks decreased to too few to represent a commodity.

Acceleration of Eutrophication

Littoral zones and meadows in lakes are important transition zones (Jørgensen, 1990) which can promote deposition of suspended solids and remove organic and inorganic material from water that flows through them. The rational harvesting and utilization of vegetation in littoral zones and meadows is a main pathway of transformation and transportation of substances, especially nutrients including N, P, C, S, etc., from lake to surroundings. This can contribute to the purification of the water and to the material balance in a lake. The decrease in macrophyte production due to reclamation, as well as excessive harvest of microphytes in lakes, reduces the amount of nutrients removed from the lake, thus reducing the amount of transformed and transported nutrient through macrophytes, and increasing that through phytoplankton, which promotes the increase of phytoplankton production and standing crop and decreases transparency and compensation depth. Therefore, a portion of the original photic zone becomes a dysphonic zone where submergent plants can no longer grow, because this changed portion lacks enough solar flux for photosynthesis. The harvest of phytoplankton is more difficult than that of macrophytes, and their turnover time is usually shorter than that of macrophytes, so that the nutrients increase further and promote the increase of phytoplankton production and standing crop, and further decrease the transparency and compensation depth, forming a vicious cycle. Such a process is repeated again and again resulting in accelerated eutrophication. Finally, all the macrophytes completely perish in the lake. The lake becomes a phytoplankton responding type from a macrophyte responding type. Such a problem and process has occurred in many middle-sized and little Chinese lakes.

Decline of Supply of Fodder, Fuel, Fertilizer and Raw Materials for Some Industries and Sideline Production

Many harvested tender macrophytes from littoral zones and meadows are usually used as fodder for cultured fish, domestic fowl, sheep, pigs and oxes; some of them, such as reeds, wild rice and cattail, can be used as raw materials for making paper and weaving straw mats and cattail bags; they are also a main source of fuel and organic fertilizer for people in the surroundings of the lake. Reduction or loss of production and harvestable amounts of macrophytes with the decrease or loss of littoral zones and meadows not only reduces the amount of nutrients removed from the lake, but also causes the people living near the lake trouble in obtaining fodder, fuel, organic fertilizer and the raw materials for some industries and sideline production. This occurred in Lake Baiyangdine, Dongtinhu, Poyanghu, and many lakes in the Northern region of Jiangsu Province.

3.3.3 Degradation of Water Quality in Some Chinese Lakes

Degradation of water quality is one of the common problems facing endangered Chinese lakes. Their main manifestations are eutrophication, salinization and acidification.

3.3.3.1 Eutrophication

Although eutrophication is a phenomenon of the natural developmental process of lake evolution, the speed and scope of lake eutrophication induced by human activities is now accelerating. For example, based on surveys on eutrophication for 34 Chinese lakes during 1978-1984 (Wang et al., 1989) eutrophic and hypereutrophic lakes occupied 26.5% of the total number of surveyed lakes and 1.503% of the total lake area surveyed (Table 3.2). This result shows that the speed of organic pollution and eutrophication in little and middle-sized lakes is faster than that in big lakes; and that the degree of pollution in urban and suburban lakes is more serious than that in common lakes.

Among the integrated impacts leading to eutrophication are external causes, such as excessive nutrients and organic matter from municipal and industrial wastewater, which go beyond the lake's buffering capacity and self-purification capability; reclamation, and some water conservancy projects, etc.; and internal causes, such as changes of the lake's ecosystem structure and function, resulting in a decrease of buffering capacity and self-purification capability, destruction of the original optimal material balance, etc.. Internal causes are the basis of eutrophication of a lake, and external causes are the conditions of eutrophication. The external causes operate through the internal causes.

Table 3.2 Trophic state of 34 Chinese lakes survived in 1978-1984

Trophic state	oligo-meso-eutrophic	meso-trophic	meso-eutrophic	eutro-phic	hyper-eutrophic
Number of lake	7	8	10	7	2
Percentage of Total number surveyed lakes	20.6	23.5	29.4	20.6	1.5
Area of Lake (km^2)	5,870.8	3912.5	9,134.1	66.55	7.31
Percentage of total area of surveyed lake(%)	24.2	36.7	37.6	1.5	0.003

Pollution Sources and State

According to incomplete statistics from 34 Chinese lakes (Wang et al., 1989), the mean daily wastewater discharged from point pollution sources made up 74.5-98.9% of each lake's pollution sources. Their total amount is about 5,646,100 tons/day, 7.05% of the total daily discharge of all municipal and industrial wastewater of China. Among the point pollution sources, 619,000 tons/day of wastewater from urban and suburban areas and factories around the lakes flowed directly into these lakes, 11% of the total amount from all point pollution sources; 5,027,100 tons/day of municipal and industrial wastewater was discharged into these lakes through their inlet streams and rivers, 89% of the total amount from all point pollution sources. This shows that in general the inlet streams and rivers are the main point pollution sources. Based on the input of organic matter, the nonpoint pollution sources only make up 3.1 to 7% of each lake's pollution sources. This shows the pollutants in these surveyed lakes, especially in urban and suburban lakes, come mainly from point pollution sources. Pollution sources without fixed sites, such as ships and boats sailing over the lake, tourists, and fodder for fish culture, do not in general play an important role as pollution sources, except in a few touring lakes or lakes used for intensive culture of fish.

Table 3.3 Nutrient salts sources in three urban lakes

Lake	Kind of nutrient salts	Total	sources of nutrients salts					
			Municipal wastewater		Discharge from catchment		Precipi- tation	
		t/a	t/a	%	t/a	%	t/a	%
Donghu	TN	747.81	517.24	89.17	158.74	21.30	53.47	7.15
in Wuhan	TP	66.93	42.65	63.72	17.0	25.40	1.17	1.75
Xuanwuhu	TN	83.11	70.32	84.60	8.7	10.50	0.59	0.70
in Nanjing	TP	12.89	11.50	86.50	0.8	6.20	0.53	4.20
Moguhu	TN	652.04	341.91	52.44	8.89	1.36	1.36	3.56
in Xinjiang	TP	49.18	28.52	50.02	3.45	7.01	7.01	0.17

The nutrient salt sources in most of these surviving lakes, especially in some urban and suburban lakes, mainly came from municipal wastewater, including domestic and industrial wastewater. For example, in three eutrophic lakes, 52.44-88.50% of nitrogen sources and 50.2- 86.5% of phosphorus sources came from municipal wastewater (Table 3.3).

High Nitrogen Concentration in Some Lakes

The nitrogen content in most suburban and urban little lakes, and a few big and middle-sized lakes, were high. Based on surveys of 9 suburban lakes (Jin et al., 1990), the mean annual NH_3-N concentration ranged from 0.262 mg/l, and in approximately 80% of the surveyed lakes was over 1 mg/l, especially for Lake Moshuihu in Wuhan City, where the NH_3-N content reached as high as 17.849 mg/l, about 90% of TN. The NO_2-N contents in these lakes were also high, ranging from 0.045 to 0.393 mg/l, and in about 60% of these lakes was over or approximately 0.10 mg/l. The NO_3-N contents of these lakes were different, one half of them less than 0.3 mg/l, some more than 1 mg/l in Lake Xuanwuhu in Nanjing, Xihu Lake in Hangzhou, and Lake Gantanghu in Jioujiang. The TN contents of these lakes ranged from 2.2-20.82 mg/l. Approximately 50% of these lakes had TN contents more than 4 mg/l, 4 times that in big lakes. In a few big lakes, such as Lake Chaohu, Nansihu, and Wulansuhai, the nitrogen content was high. The NH_3-N contents were 0.951, 1.423 and 1.508 mg/l respectively. The NO_2-N contents were 0.059, 0.048 and 0.015 mg/l respectively. The NO_3-N contents had a peak value of 1.291 mg/l in Chaohu Lake. In these urban and suburban little lakes, the ratio of inorganic nitrogen to total nitrogen was generally more than 60%, which favoured promoting plant growth and production, and aggravated eutrophication, of these lakes. The ratios of NO_2-N/TN, NO_3-N/TN and NH_3-N/TN were generally less than 5%, 50%, and more than 60% respectively in most of these lakes, and the NH_3-N contents were usually more than the NO_3-N content, showing that these lakes were seriously polluted by urban sewage, and were mainly in the denitrification state, aggravating eutrophication and decline of water quality.

High Phosphorus Contents in Some Lakes

The phosphorus contents of surveyed urban and suburban little lakes were generally higher than those in most of the big and middle-sized lakes. The TP contents ranged from 0.089-1.028 mg/l and their mean value was about 4 times of that in middle and big lakes. The highest TP contents were 1.028 and 0.967 mg/l in Lake Moshuihu in Wuhan City and Xuanwuhu in Nanjing City. Their inorganic soluble phosphorus ranged from 0.023-0.181 PO_4-P mg/l; that of approximately 80% of these lakes was over 0.05 mg/l. The highest PO_4-P contents were 0.122 and 0.181 mg/l in Lake Moshuihu and Xuanwuhu. This shows that the phosphorus accumulation was serious. Both of these lakes had developed to a hypertrophic state, where the chlorophyll concentration in the lake water reached as high as 215.75 and 168.14 mg/l. The ratios of PO_4-P/TP in all the surveyed suburban lakes were over 10%, reflecting a glut of phosphorus related to the input of municipal sewage.

Decline of the Self Purification Capability in Some Lakes

The self purification capability and buffering capacity in some lakes have declined so that the optimal structures and functions of the lake ecosystems were disturbed or destroyed. For example, besides the destruction and decrease or loss of microphytes in some lakes the self-purification capability and buffering capacity mentioned above also reduced. Continuous and gradual loss of self-purification capability and buffering capacity also resulted from changes of some of the consumers in lake ecosystems, such as silver carp and bighead carp, which are migratory fish and mainly feed on plankton and organic detritus. These decreased or disappeared in some lakes, because their migration pathways between these lakes and rivers were hindered or stopped by water conservancy facilities and/or reclamation; the snails which mainly fed on sessile and sedimental algae decreased or disappeared in some lakes because of over-catching or over-utilization. This resulted in some links and pathways of the food web for transfer, transformation and recycling of some nutrients being weakened or stopped. Excessive increase of herbivorous animals such as grass carp, crabs and crayfish in some lakes by stocking caused similar effects to destruction of microphytes, because the vegetation was over-eaten by them, inducing a series of chain reactions and decreasing the transfer, transformation and recycling of nutrients.

3.3.2 Salinization of Some Lakes

Salinization in lakes is a prominent problem in the arid and semiarid regions in China. Although this was mainly influenced by the arid and semiarid climate, which made the evaporation from lake surfaces exceed the precipitation on the lake surface thus concentrating the lake water, some human activities which decrease the compensation water of the lake could aggravate the salinity of these lakes. For example, the salinity of Lake Boston, a large influent-effluent lake in a semiarid region of Xinjiang Uigher Autonomous Region, was 0.3 g/l in the early years of the 1950s. After the 1950s the water for irrigation from the catchment of the lake was increased with the enlargement of irrigated fields from 2-3 billion m^3 /a in the1950s to more than 20 billion m^3 /a. In addition, the irrigated return water, with a high concentration of salt, was discharged into the lake. Therefore, the salinity of this lake water increased to 1.8 g/l in the 1980s, and the lake became a slightly salt water lake from a freshwater lake. In a manner similar to this lake, according to our institute survey, the salinity, pH value, and contents of K^+ + Na^+, SO_4^-, and Cl^- were increasing, while the content of HCO_3^- was decreasing in two series of connected lakes, Lake Jili and Lake Bulantuo in Xinjiang Region because the inflow from the main inlet river was decreasing with the enlargement of the fields and the increase of water for irrigation in the catchment of the inlet river, from 8.03 billion m^3/a in the 1950s to 6.60 billion m^3 /a in the 1970s. In particular, in 1984, a sluice gate was established in the outlet of Lake Jili to control its outflow which is also the inflow to Lake Bulantuo from this lake. This has usually caused the inflow of Lake Bulantuo to be stopped since 1974. Based on calculations and forecasts, the area and storage of Lake Bulantuo should decrease to 265 km^2 and 3.63 billion m^3 and its salinity should increase to 57.85 g/l in 2000 from 753 km^2, 60.2 billion m^3 and 3.35 g/l in 1987, if its inflow, precipitation and evaporation do not greatly change during the period of calculation.

3.3.4 Decrease of Community Diversity

Because of the impact of hydrological and related physical changes and decline of water quality on the habitat and living conditions of some species of organism, in addition to over-fishing and hunting, and/or excessive harvesting and utilization of some plants and inappropriate introduction of exotic species, the community composition changed and diversity decreased in some lakes. For example, because the migration pathway between some lakes and rivers was stopped or separated, some migratory fishes, such as Eels (*Anguilla japonica*), hila herring (*Macrura reevesii*), black carp, grass carp, silver carp, bighead carp and crab (*Eriocheir sinensis*) disappeared in some lakes. Many species of fish which originally lived in Lake Boston disappeared because of inappropriate introduction of the exotic carnivorous species Red perch (*Perca fluviatilus*). Excessive stocking of grass carp resulted in the elimination of most of the aquatic vegetation in some lakes. Hydrological and related physical changes made two species of local fish become endangered species in Lake Erhai. Destruction of the littoral zone in some lakes decreased the number of species and abundance of waterbirds and migratory birds including some species endangered in Asia or the world.

As shown by Jørgensen and Mitsch (1989), "Chemical and biological diversity contribute to the buffering capacities of ecosystem. The more possibilities the ecosystem possesses, the higher its buffering capacity. This is especially true for the buffering capacities related to the function of the ecosystem." The decrease of biological diversity should weaken buffering capacities and self-purification capability.

3.4 PRINCIPLES, METHODS AND MEASURES FOR SUSTAINABLE UTILIZATION, PROTECTION AND RESTORATION OF THE LAKES

Based on the main problems facing endangered lakes and their causes, the lessons from failures and from successful experiences in protection, sustaining utilization and restoration of the lakes, some principles, methods and measures for conservation and restoration of lakes are summarized and suggested for discussion with readers.

3.4.1 Holism Principle

It is a common lesson in the protection, sustained exploitation and utilization of lakes to violate or neglect the holism of a SENCLE. Each of the different organizations related to the management, exploitation and utilization of a lake, such as that of fishery, supply and drainage water, water conservancy, reclamation, agricultural irrigation, shipping or tourist trade, protection, etc., usually takes its own selfish course and violates or neglects the other functions in a lake, and lack the holistic and systematic viewpoint. Activities which are self-absorbed and do not consider the general interest result in many contradictions between part and whole, one part and another part, nature and economics, present and future. Many examples of this have been mentioned in 3.1-3 above. Therefore, it is important to take the holistic and systematic viewpoint as a guideline to the utilization and protection of a lake. Although the main objectives and functions of various lakes or of a single lake may be different in period, it is necessary that unified planning, with due consideration for all, ensures the main aims along with rational development of other functions. As is known to all, SENCLEs are like any system, showing interdependency, interconnectedness, interinhibition, and causal multiplicities (interactive loops) among the components of its structures and functions, and between both structures and functions. The appearance, action, function, dynamics and change of every component in the system can always be affected more or less by other components or elements, without exception, and is always the result of the causality effects of two or more different components, and collective effects of a SENCLE.

Under the guideline of holism, some structures and functions which disturb the whole and/or future interest in a lake should be regulated. In short, in order to maintain the holism of a SENCLE, coordination of management efforts is needed. One of the better methods to implement the holism principle in the integrative design, management, exploitation and utilization of a lake may be system engineering, modelling an optimization model as the basis of determining the strategies, designs and applications about the SENCLE, based upon quantitative research on the dynamics of the functional flow between eco-base and eco-pool; and on the cybernetic relationships between the eco-core and eco-base.

3.4.2 Harmony and Balance Principle

Many of the examples mentioned above have shown that disharmony and imbalance usually cause the various problems facing endangered Chinese lakes. The harmony and balance between the eco-base and the eco-pore, the eco-core and eco-base, and within the eco-base of a SENCLE are the foundation and guarantee of its healthy and stable development. For stable and harmonious existence of a lake ecosystem there always exist certain limiting factors as well as a negative feedback mechanisms to restrict its development, and certain leading factors as well as positive feedback mechanisms to promote its development. In a stable and harmonious lake ecosystem or SENCLE, the positive and negative mechanisms balance. The negative feedback function dominates over the positive feedback functions. Any quantitative growth of structure which does not conform to the overall functions is not allowed. All manufacturers should put first the utility of their products instead of their quantity. Therefore, while regulating a lake ecosystem or SENCLE for protection, exploitation and utilization, or restoration, special attention must be paid to the dynamics of the leading and limiting factors, and to the position and intensity of the positive and negative feedback loops, by analyses and measures suitable to local social, economic and natural conditions. The methods can be divided into two major categories as follows:

3.4.2.1 Control and/or Regulation of the Eco-pool of a SENCLE

In a SENCLE, the forcing function or the input to and output from the eco-base (a lake ecosystem) are the external variables. When these are optimal and harmonious with the eco-base, they are supporting factors and conditions for the healthy existence and stable development of a lake ecosystem. Therefore, it is a necessary condition for protection and sustainable utilization of a lake to maintain the optimal forcing functions; otherwise, if they are too much or too little, they could destroy the lake ecosystem or SENCLE. It is therefore a necessary condition for the restoration of the lake ecosystem to regulate the forcing functions or the input to and /or output from the lake.

3.4.2.1.1 Regulation of Nutrient Input for Control of Eutrophication

High nutrient loading can promote lake eutrophication and the formation of algae blooms. The general way to reduce nutrient loading of lakes is to eliminate or reduce nutrient and organic matter input into them from their watersheds. This can be accomplished by several measures as follows:

Interception and diversion of sewage: In general, wastewater effluent is rarely diverted out of watersheds because of the difficulty of finding an alternative site, but a few diversions in urban and suburban lakes have occurred. In Lake Xihu (West Lake), Hongzhou, 67.4% of municipal wastewater effluent in its watershed has been diverted from the lake to a sewage treatment plant since 1982. The interception and diversion of wastewater reduced the artificial loads of 71.3% of N and 73.9% of P and the increased COD load. This prevented further worsening of water quality in this lake, but the lake remained eutrophic because abundant nutrient and organic matter stored in benthic deposits and bottom clay were continuously released to the lake water.

This measure had also been applied in Lake Xuanwuhu, Nanjing and Lake Donghu (East Lake), Wuchang by the last year of the 1980s. The result of the diversion was similar to that in Lake Xihu.

Detention basin: This has been used in many lakes in the Jianghan Plain for impounding storm water runoff (urban and agricultural). After the water had been retained for a long time to allow settling of particulate materials, the organic matter and phosphorus concentration and the amount of these discharged into lakes should reduce, because much of the organic matter, phosphorus and some other contaminants in runoff water are associated with suspended particulate matter. Detention basins are effective as a low-cost, low-maintenance treatment system for reduction of nutrient and other contaminants. This measure may be carried out to suit local conditions.

Pre-reservoir detention reservoirs are a variation on the same idea. A total of 97 pre-reservoir reservoirs have been constructed on natural streams upstream from their entry to Lake Baiyuandin, the biggest lake in North China. These reservoirs intercepted and related about 31.5 billion m^3 of water a year, including municipal sewage and industrial and agricultural waste water. Such reservoirs contribute to reducing the amount of silt, nutrients and other contaminants input to the lake, but they also decrease the annual inflow to the lake because these were excessive.

Treatment of municipal and industrial wastewater in the Lake watersheds: Wastewater treatment plants or workshops are used to purify municipal sewage and/or industrial wastewater by a series of physical, biochemical and artificial chemomechanical treatment processes. These measures are being applied in some lake watersheds. Although they result in higher efficiency of purification of wastewater and reduction of input of pollutants to the lakes they usually need great investment and complex equipment, as well as some consumption of electric power or other technological energy. Therefore, it is usually difficult to use them widely in extensive lake watersheds for controlling the nutrient and other pollutants put into lakes, especially in under-developed regions of developing countries, because of the limitations of investment, technology and energy sources.

Ecological engineering measures for treatment and utilization of wastewater are being applied in some lake watersheds. In general, these measures need lower investment, and they are solar-based systems, and so need little or no technological energy, and most of the equipment is supplied by nature (Yan & Ma, 1991). These measures have been applied in a few parts of several lake watersheds for treating municipal or industrial wastewater. For example, ecological engineering has been applied to purifying industrial wastewater containing high concentrations of organic matter (COD more than 10630 mg/l; BOD_5 more than 3950 mg/l; TSS more then 5,300 mg/l), nitrogen (TN more then 1035 mg/l; NH_3-N 12.5-54.2 mg/l) and phosphorus (PO_4-P 80-90 mg/l) from a silk reeling mill in Danyun County, a part of the Lake Taihu watershed (Yan et al., 1993). The large quantities of protein and fat in the wastewater were first reclaimed using biochemical methods. The retrieved protein and fat were used as the raw material for producing fine fodder for pigs, domestic fowl and cultured fish. A semi-artificial aquatic ecosystem in a wastewater discharge canal, consisting mainly of hydroponic cultivation of vegetables (i.e., spinach and celery) and water hyacinth was used to further purify the wastewater to meet discharge standards. The purification rates were 95.7%, 92.6%, 96.6%, 86.6%, 79.8% and 88.7% for TSS, BOD_5, COD, TN, NH_3-N and PO_4-P respectively. The vegetables produced are used for human consumption. The harvested water hyacinths are used as green fodder for ducks, geese, and cultured fish. This kind of ecological engineering has also been used in Zhangde City, a part of the Lake Dongtinhu watershed, for treatment of the municipal sewage from all of the old city region since 1989.

Treatment of inflow streams of lakes: In general, the inflow streams are usually the major point pollution sources in most lakes, as mentioned above. Therefore, one of the important measures for reduction of nutrient or pollution loads is to purify the inflow streams and decrease the concentration of nutrients or other pollutants in the inflow stream water. One suitable measure is to divert the water of these streams into natural or semi-artificial wetlands depending on local conditions, then discharge these to the lake after the nutrients are absorbed and transformed by the wetlands. Because this measure is limited by geographical conditions, it cannot be universally applied. Ecological engineering for treatment and utilization of polluted water can also be used in some lake inflow streams. For example, ecological engineering in Fomenting River, a major inflow stream of Lake Dushuhu, Suzhou has been operating continuously for more than 10 years (Yan 1987; Ma & Yan, 1989; Yan & Zhang, 1992). Since 1983, less than 3 ha (in the years before 1987) to more 10 ha (in the years after 1988) of water hyacinth (from May to November every year) and Azolla (from September to next May every year) were planted in a section of this stream 2386 m in length. The annual output of these plants was from less than 6,000 tons (before 1987) to approximately 20,000 tons (after 1988). A great amount of nutrients and pollutants, including 500 to 2,000 tons of organic matter, 65 to 200 tons of nitrogen, 4 to 13 tons of phosphorus and 3 to 10 tons of sulphur per year were transformed and removed from this stream with the harvest of these plants. This ecological engineering not only decreased the concentration of nutrients, thus reducing the nutrients load of Lake Dushu, but also provided a great amount of low cost, good quality green fodder of cultured fish, domestic fowl and pigs, and greatly increased the economic interests of Lufu Fishery Farm. This was also the reason why the ecological engineering could be continued and sustained.

3.4.2.1.2 Dilution and Flushing by Diversion

Dilution and flushing is a procedure to lower water column nutrients in a lake, especially phosphorus concentration, and to increase the water transparency and wash out algae cells, by adding clean water. By 1986, a diversion line 3.137 km in length, including a tunnel of 1.605 km from Qingtang River to Lake Xihu and with a maximum diversion capability of 300,000 m3/d, was constructed for dilution and flushing of the contaminated water of the lake. Although the ability of water diversion has not yet fully been used because of some temporary conditions, the water diversion has operated for a score to scores of days each year since 1986. For example, in 1988, the water conversion continued for 57 days and added 13.12 million m^3 of water to the lake over the year, about 47.7% of the total input of water to this lake, and 1.1 times its volume. The result measured 15 days after diversion, in December 1988, compared with the initial data before diversion showed that the lake's flushing rate was increased and the rate of reduction of TP concentration was 21.6 to 83.1% in five different areas of the lake. However the phosphorus concentration gradually rose and was restored to its original level after diversion stopped. It was only temporarily effective to control water column phosphorus concentration. The phytoplankton increased to 192 species in 1988 from 118 species in 1981 before diversion, its mean density decreased to 58.72 million ind./L in December 1988 after dilution from 209.26 million ind./L in November 1987 before diversion, but it rose to 157.96 million ind./L in January 1989, soon after diversion stopped. The diversion did not markedly improve the transparency in this lake, because the increased flushing promoted resuspension of sediments and increased the release of nutrients stored in the benthic deposits (Lu et al., 1992).

The application of this measure is usually limited by the quantity and quality of the water sources for diversion, so that it can only be used with suitable local conditions. In addition, the contaminated water flushed from the lake to another place may induce or aggravate pollution there.

3.4.2.1.3 Treatment of Agricultural Runoff in Lake Catchments

Agricultural runoff in lake catchments is usually a major nonpoint pollution source of a lake. Its treatment is important to control or eliminate nonpoint sources of pollution. There are two objectives and pathways to achieve this: runoff control and nutrient loss control in the watershed of the lake.

Runoff Controls by Free or Minimum Tillage: This measure not only saves labour but also decreases losses of soil, nutrients, and other contaminants from agricultural land. Free tillage has been tried in the catchments of some lakes, such as the suburban and rural area of Suzhou, where it is still in the development stage. The effectiveness in preventing nutrient export, technical feasibility, social acceptability, and economic benefits vary widely among the practices and are being summarized by some Chinese agriculture research institutes.

Crop Rotation: This is a part of Chinese traditional measures of agriculture. Crop rotation not only utilizes time and trophic niches as fully as possible (Yan & Zhang, 1992), but can also contribute to preventing water and nutrient losses because fields are covered by plants in all or most seasons in a year, which can reduce the losses of soil, nutrients and water. This measure has been widely applied in most regions of China including many lakes' catchments and has had some effect in controlling nonpoint nutrient sources in some lakes.

Terraces: The terraced field is a kind of farmland composed of many levelled fields constructed along the contour lines of sloping ground in hilly or mountainous regions. Terraces can change the degree of topographic slope, and give play to the functions of retaining water and intercepting silt, preventing soil and water erosion, and change of volume and peak flow. In order to control agricultural runoff in lake catchments, the construction of terraces on sloping ground with steep slopes is one of the usable and effective measures for runoff control. This measure has been used to protect water and soil in the watersheds of some lakes which are rich in sloping ground.

Nutrient Loss Control in Lake Catchments: Nutrient loss in the catchment of some lakes is very serious and is another cause of nutrient loads of lakes. Several measures for controlling nutrient losses have been used.

Rational Fertilizer Application: An excessive amount of fertilizer application is an important cause of nutrient loss. For example, the mean annual amount of applied chemical fertilizer in farmlands of the watershed of Lake Taihu was 1,545 kg/ha in 1979, which was 660 kg/ha higher than that in the whole of Jiangsu Province and greatly exceeded the absorbable and utilizable amount of plants cultivated in that farmland. The amount of lost fertilizer from these fields was 53% of that applied. Based on calculation, the amount of lost fertilizer in the whole catchment of Lake Taihu was about 100,000 tons a year during the 1970s before 1978, and most of this was brought into lakes through runoff. Therefore, rational decrease of the amount of fertilizer applied, based on the different backgrounds of nutrients in various soils and areas, as well as the amount of nutrient absorbable and utilizable by various cultivated crops is a usable and effective measure for nutrient loss control.

Some traditional Chinese agricultural measures can contribute to nutrient loss control, such as timing and frequency of fertilizer application, crop interplanting, intercropping, and rotation with legumes or other green manure, composting, and storing manure during winter. These measures have been extensively applied in the catchments of some lakes to reduce nonpoint nutrient sources.

3.4.2.1.4 Water and Soil Conservation

Excessive silt discharge to lakes because of water and soil losses in their catchments is one of the main causes of hydrological and related physical changes as well as eutrophication. For the solution to this problem, water and soil conservation is a basic and necessary pathway. In China, great efforts towards water and soil conservation are being made. A series of laws and decrees about protection of forests, pastures, water sources, etc., have been made and are being enacted. Especially, great reforestation and afforestation projects for improving regional environments, including the catchments of many lakes, are being carried out. For example, in order to solve severe soil erosion and flooding in the catchment of upper and middle Changjiang River, where soil and water losses and silt discharge and deposit in the lakes in the catchment of the river has increased, a programme in Changjiang River Shelter-Forest system was designed to increase the forested area of this region by 20 million ha over a 30- to 40-year period. In 1990, this programme was implemented in 39 counties and 90,000 ha of forest were planted. The implementation expanded to 93 counties in 1991 (Office of Environmental Protection of Chinese Ministry of Forestry, 1991). When the first stage of this program is complemented, 6.7 million ha of forest area will have been planted before 1999 and will greatly decrease the silt discharge into and deposit in lakes in this region.

3.4.2.1.5 Combining Conservation with Rational Catch and Harvest in Lakes

Organisms in lakes are a kind of renewable resource; they can grow and reproduce. Harvest and catching are forcing functions, and are also a link and pathway of output of material from the lakes. Over-fishing and/or over-harvest could induce changes or destruction of the community composition, material balance and a series of lock reactions. So it is important for lake conservation to protect the organisms in a lake. However the population growth curve shows that the growth rate of a population decreases with the increase of its density. If the organisms in a lake are only protected without rational use to adjust their density by removal from the lake, the density of the population will reach carrying capacity. This not only may reduce bio-production and transfer and transformation of substances in the lake, but can also cause secondary pollution by partial decomposition and accumulation of organismal remains. For example, in Lake Quinghaihu, Naked carp (*Gymnocyprins prezewaskii*), was one of the predominant species of fish in the lake, but its growth rate and population production were very low, because the population density of this fish was very high and attained its critical standing crop (CSC) as a result of conservation by long-term closed fishing in the lake before 1957. This caused intraspecies self-regulation of this fish population under high population density, namely negative feedback was dominant, the age of sexual maturity was delayed, the mean amount of spawn of each fish and the growth rate decreased. Since 1958, when this fish has been exploited, although the total standing crop and density of this fish population has decreased gradually, the annual production of its population increased gradually as the sexual maturity age of most individuals has increased, and the mean amount of their spawned eggs and growth rate has increased gradually by intraspecies self-regulation under low density of population (Zhang & Cheng, 1980). Another example is in Lake Gehu where, because of the closed harvest of aquatic plants for a long time, and inhibited stocking of herbivorous fishes, the aquatic vegetation, especially the submerged plants, grew luxuriantly and filled the whole lake. This not only promoted swamping and blocked navigation in the lake, but also caused secondary pollution by their remains: every winter and early spring, when most of the vegetation in the lake cannot grow, the COD, BOD and soluble humus and nutrient concentration in the lake water greatly increased, and the dissolved oxygen concentration decreased.

Thus, in order to conserve a lake, the protection of aquatic macrophytes and fish should be combined with their rational use. An example of the combination of conservation with rational use of aquatic vegetation is the East bay of Lake Taihu. This bay is 13,507 ha in area of which 13,334 ha is aquatic macrophytes, including 9,334 ha of submerged vegetation, 3,467 ha of wide rice (*Zizania latifolia*) and 533 ha of reeds. Their total production is about 567,800 tons in fresh weight per year. A total of 278,000 tons of aquatic vegetation, or about 49% of the annual production of these plants in this bay, were harvested and removed from this lake every year, to be used as green fodder for cultured fish in the ponds, domestic fowl and pigs, and some raw material for building and fuel. This is equivalent to 917 tons of nitrogen and 137 tons of phosphorus removed from this bay. In addition, about 270,900 tons/a of aquatic vegetation or about 48% of the annual total production of aquatic macrophytes in the bay, were grazed by stocked fish in the lake. This contributed to the material balance and eutrophication control. Although this bay is situated downstream and receives a great amount of contaminated water, the COD, TN, TP, soluble nutrients concentration and phytoplankton biomass and production in this bay is less than that in all other areas of the lake. This result proved that the combination of rational harvesting and the use of macrophytes with conservation can contribute to improving water quality and material balance as well as providing economic benefits (Yan & Zhang, 1984).

When the quantity of substances put into the lake, such as nutrients, silt or water, is greater than the lake's output and buffering capacities, the superfluous substance takes the form of waste or pollutants accumulated in the lake or discharged to its surrounding. This causes eco-imbalance and environmental pollution or destroys the structure and function of the lake ecosystem. This phenomenon is called ecological stagnancy. On the other hand, if the quantity of substance output from a lake exceeds that of input to it, this causes resource exhaustion, decrease of bio-production, transformation and regeneration of some renewable resources, and material imbalance. These phenomena can be used to measure the level of ecological stagnancy or exhaustion. When the ratio is more than 1 it means that ecological stagnancy is present, so some measures should be taken or improved to speed up and increase the output of the superfluous substance and/or to delay and decrease the input of this substance. If the ratio is less than 1, ecological exhaustion is present, so some measures should be taken to increase the input of this substance and/or decrease its output. This is the theoretical basis of rational harvest and catching.

3.4.2.1.6 Product Modification

Modification of some products, such as pesticides, laundry detergents, fertilizers etc., has been an effective and successful method for control of pollution sources in many countries including the USA (Maki et al., 1984). These experiences are being learned by China. For example, since the 1980s, a legislative ban of the production and use of organic chloride pesticides has been enacted in the whole of China. This is reducing the input of and pollution by organic chlorides in lakes. Decrees banning phosphate or requiring lower levels of phosphates in laundry detergents have been enacted in many Chinese provinces. The application of slow release fertilizers is spreading. These modification of some products are also one of the measures for control of forcing functions of lakes.

3.4.2.2 Control and/or Regulation of the Eco-base of SENCLEs

The activities in the eco-base of a SENCLE, namely in the lake ecosystem, is the basis of the dynamics, change and development of a SENCLE. According to Chinese philosophy and ecological theory, the fundamental causality of development, including the dynamics and change of an ecosystem or an object, is internal to the object or ecosystem. It lies in contradiction within an ecosystem or a thing itself. This internal contradiction exists in every ecosystem or every single thing, in its motion and development; within an ecosystem or inside an object is the fundamental cause of its development, while its interrelations and interactions with other external factors or things are secondary causes, i.e. external causes are the conditions of change and internal causes are the basis of change. External causes operate through internal causes. From this viewpoint, the relative stability and change of an ecosystem is mainly determined by the structure and function of the ecosystem, namely by the internal causes; the forcing functions, or external causes, such as input and output of material and energy are also conditions of relative stability and change (Yan & Ma, 1991).

3.4.2.2.1 Returning Reclamation Districts to Lakes

In order to adjust the destroyed physical structure and function of a lake, besides limitation and control of new reclamation to maintain the whole interests of a lake or a region, some of the reclamation districts which have seriously destroyed the coordination among the many functions in a lake or a region should be returned to the lake in a planned way and in accordance with the actual situation. Some suggested standards for the reclamation districts required for returning to the lake are that: any reclamation districts are under the stipulated water level; seriously interrupt the flood discharge or inflow; occupied the main spawning ground of dominant species of fishes in the lake; and the input including material and financial resources, and labours in the reclamation district is more than the output. Based on the needs for water conservation, the ratio (S_l /S_r) of the lake surfaces (S_l) after reclamation districts have returned to the lake to its catchment area (S_l) should reach 8-15%. Since the 1980s, a few reclamation districts have returned or are returning to some lakes in China, but this needs to extend further.

3.4.2.2.2 Sediment Removal

Full-scale sediment removal in a lake can not only adjust or improve some of the internal physical structure and functions of a lake ecosystem, such as increasing lake depth, increasing volume and regulating storage, but can also control internal loading because loading from phosphorus and nitrogen is greatest from the most recent phosphorus and nitrogen-rich surfacial layer. On the other hand, the dredging procedure is usually a gigantic project which costs too much, and needs provision of an adequate containment area for the sediments. So this procedure is only suitable for application in some little lakes or in a few parts of some middle-sized lakes.

In the early years of the 1950s, approximately the whole area of the bottom of Lake Xuanwuhu, Nanjing and Xihu, Hangzhou was dredged up. Just after the accomplishment of this dredge project, the mean lake depth in both lakes increased to about 3 m from just over 1 m before the dredge, and the lake water cleared. But this condition was only maintained for a few years. The mean lake depth decreased to less 2 m in the 1960s from about 3 m, and the two lakes became eutrophic and hypereutrophic. This can be compared with the effects of a part dredge project in Lake Xihu in the 1070s, more than 900 years ago, organized and directed by Su Dongbo (1037-1101), a mayor of Hangzhou City in the Son Dynasty. Based on historical records, it was similar to the recent dredge project in that the mean lake depth of Lake Xihu deepened to about 3 m from just over 1, but it differed from the recent dredge project in the time of maintaining its effects. The lake depth only just decreased to less than 2 m from about 3 m in approximately 300 years. Why was the time of maintaining the dredge effect of the recent dredge project much shorter than that in the Son Dynasty? The inference is that, besides a little difference of silt discharge between recent times and in the Son Dynasty, the difference of community composition in the lake after the recent dredge and in the Son Dynasty may be the principal cause. According to the historical record, there were still abundant aquatic macrophytes in Lake Xihu soon after the dredge in the Son Dynasty, because the dredge at that time completely depended on labour by handworkers with low work effects. Only small pieces of the bottom were dredged one after another over a longer time. Therefore, although the benthos in the dredged area had to be destroyed the benthos in the part of the bottom that was not dredged had time and a chance to transfer, grow and reproduce in the new dredge area. So the benthos, including many aquatic macrophytes and benthic animals, was restored in the whole lake soon after the dredge. Harvesting of these macrophytes and fishing were continued for a long period. The recent dredge used a dredger with a higher work effect. Therefore, all regions of the bottom of the lake were quickly dredged in a shorter time. The benthos of the whole lake were completely removed in a short time and did not have enough time to restore themselves. After 40 years, aquatic macrophytes and snails have not restored themselves in most regions of this lake. The disappearance of this benthos and a series of lock reactions induced by the dredge resulted in the loss of many important links of the original food chain and web, changing the pathways of substance transfer, transformation, and cycling in the lake, stopping the route of output by harvest and utilization of macrophytes, reducing the catch of fish and snails, and promoting the production of phytoplankton in the lake. The turnover rate of phytoplankton is very high, so that their great production and standing crop increased more and more. Because the harvest of phytoplankton is difficult, besides the little phytoplankton discharged out of the lake, most of it remained in the lake and formed an important internal suspended load source. This accelerated the sedimentation and increased the sediment accumulation.

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CHAPTER 4

ENVIRONMENTAL PROBLEMS OF LARGE CENTRAL ASIAN LAKES

Genady N. Golubev

In the middle of the Euro-asian continent there is the largest closed area in the world with a territory of four million square kilometers. The rivers within this area usually end up in quite a number of closed lakes. Two of them are so large that they are traditionally called seas. The largest lakes are: Caspian Sea, Aral Sea, Lake Balkhash and Lake Issyk-Kul. Approximate morphometric data on them up to about 1970 are given below.

Lake name	Lake area, in km^2	Maximum depth, in m
Caspian Sea	370,000	1025
Aral Sea	64,500	68
Balkhash	18,200	26
Issyk-Kul	6,300	702

The main feature of any closed area is that all the precipitation falling on it eventually evaporates from the area. The river run-off originating from the precipitation comes down to the terminal lakes or marshes and evaporates from them. The closed lakes are very sensitive to the changes in their water balance quickly reacting to them by altering their main morphometric parameters which manifests in the changes of the water level. Dissolved salts content in the lakes' water also quickly reacts to the water balance changes. The morphometric and geochemical variations cause many other ecological changes.

The natural variations of climate are the main reason for the alterations in the water balances of both terminal lakes and their basins. Besides, economic activity plays an ever increasing role there because if the consumptive use of water increases in the basin, less water comes to the terminal lake. Closed areas are characteristic of arid and semi-arid regions where the main use of water is for irrigation purposes which tends to grow reducing the inflow of river waters into the terminal lakes. Both development of irrigation in lake basins and, in particular, the reduction of lakes lead to serious socio-economic problems of environmental origin. In Central Asia significance of the climatic and anthropogenic factors change from place to place as can be seen from the review below.

The classic and disastrous example of the behaviour of the closed lake and the associated environmental implications is the story of the **Aral** Sea. The larger part of this chapter is devoted to the discussion of the Aral Sea case.

The Aral Sea receives only two rivers, Amudarya and Syrdarya. Some rivers like the Zerafshan, Tedzhen and Murgab, do not reach Amudarya anymore, but did so in some periods in history. Irrigation canals including possibly the largest in the world Karakum Canal stem from the two main river reducing their run-off downstream. Aral Sea serves as the main (but not the only) collector of waters in this large area.

The surface of the region gravitated to the Aral Sea is about 2 million square kilometers. Approximately 70% of this territory belongs to what used to be the USSR. It is divided between five new independent States, Kazakhstan, Kirgizstan,Tadjikistan, Turkmenistan and Uzbekistan and the rest is Afghanistan and Iran.

While the population around and near the lake shores is over 3 million, its basin contains no less than 32 million inhabitants. Most of the population lives in areas of the middle reaches of the rivers where they come out from the mountains. It is an area of ancient civilizations with millennia of irrigation, the oldest one being dated back to 6,000 years B.C. By the middle of this century the irrigated area in the Aral Sea basin was about 5 million hectares.

The Aral Sea is situated in a very arid region with annual precipitation of about 100 millimeters. In the strip between the plains and the mountains precipitation is between 400 and 500 mm and in the mountains, which is the zone of the river run-off formation, it is higher exceeding at some points 2000 mm. Total amount of precipitation in the Aral Sea basin is about 500 km^3 a year. The river run-off is about 120 km^3. Out of this amount Syrdarya and Amudarya carry from the mountains approximately 110 km^3. The groundwater resources of acceptable quality which are not connected hydraulically with the river run-off are about 45 km^3 a year.

In historic times variations of the meteorologic and hydrologic conditions in the basin were quite large and, as a result, there were pronounced changes in the state of the Aral Sea.

The water level varied within 20 m, so as it was sometime much higher and sometime lower than at present. Rise and fall of the civilisations in the basin related to development or decline or irrigation and, hence, also influenced the state of the lake.

During the century before 1960, about half of the Amudarya and Syrdarya run-off was used for irrigation and lost for natural evapotranspiration in the middle and lower reaches of the rivers. The other half flowed into the Aral Sea. The water level was oscillating within 2-3 m. The area of the Aral Sea was 66,000 km^2 (excluding the islands). The volume of water was 1,066 km^3. The maximum depth was 69 m, and the average depth, 16 m. The salinity of water was about 10 g/L. These data are commonly used now as a reference point when discussing the state of the lake.

At the end of the 1950s and the beginning of the 1960s, the leadership of the USSR made a decision on an extensive development of irrigation in the Aral Sea basin. During 1950s through to the 1970s, it was believed that the irrigation may become the main remedy in solving many agricultural and socio-economic problems. Central Asia had a prominent place in this technological fix. It was expected that the expansion of the irrigated lands would bring a drastic increase in cotton production with the subsequent increment on textile and related products. It was planned that a part of the cotton production would be exported bringing hard currency into the country. It was also expected that the region would be then the main source of fruits and vegetables for the whole country. It was thought that production of rice and meat would go up, satisfying the demand of the region. And last, but not least, all those developments would provide enough jobs for a rapidly growing population of the region.

In short, the expansion of irrigation in Central Asia should have brought prosperity both to the region and to the country as a whole. It was clear to the water resources experts and, through them, to the rulers that one of the main side effects would be deterioration of the Aral Sea. But it was deemed a small sacrifice to the shiny development prospects. Every water expert in the country knew a saying of a famous Russian climatologist A.I. Voeykov published in 1908, that the Aral Sea is a mistake of Nature because waters collected from the mighty mountain systems go finally to a sparsely populated depression and evaporate there. And the common thought was that mistakes of Nature could and should be corrected. Thus the technological fix has been combined with the narrow, sectoral support from science. Even if a comprehensive impact assessment of the development plans for the region had ever been made, it never became known either to the government or to the public. Besides, the role of the latter at that time was to applaud and not to participate in the decision making.

Since the decision on the massive development of irrigation has been made, the investments in agriculture, including irrigation, have increased drastically. For instance, in Uzbekistan, the most populated of the five Central Asian Republics of USSR, in the period from 1961 through to 1985, the investments in agriculture were about 45 billion roubles. Out of this amount at least 24 billion roubles were spent on irrigation and related activities. With the prevailing official exchange rates, these figures correspond to 64 and 34 billion US dollars. It would not be a big exaggeration to say that the investments in agriculture in the basin of the Aral Sea over the last 30 years were close to 100 billion roubles, moreover half of it went into irrigation. The area of irrigated lands in the Aral Sea basin has increased from 5 million to almost 8 million hectares now.

The consumption of water was and still is excessive because of the lack of interest in economising it. The irrigation canals are mostly unlined. The largest one is the Karakum Canal taking about 10-12 km^3 of water a year from the Amudarya River westward. It goes in many places through a sandy desert. But even where the lining was envisaged it usually has not been made because the builders after having dug a part of the conduit filled it promptly with water without putting the lining and reported on the work accomplished as it were in accordance with the design. Additional benefits for the advanced accomplishment of the construction quotas and the illegally saved materials going to the black market were the premiums for the corruption. More lining has been put, however, in the canals built more recently.

Efficiency of the irrigation systems is between 0.55 and 0.65 due to the seepage from the unlined distributing canals and a predominantly furrow method of watering. Water consumption by crops exceeds that which is necessary by 150-200%. About 17-18,000 m^3 of water is spent on average per hectare of cotton (Oreshkin, 1990) and between 25,000 m^3 and 55,000 m^3 is used for a hectare of rice (Glazovsky, 1990).

In the Amudarya and Syrdarya River basins a part of the water once used for irrigation returns into the river and can be used again. Even keeping this in mind, one can see that the development of new irrigated lands with an area of 3 million hectares would take all the water resources available by 1960 in the Aral Sea basin. With the 17,000 cubic meters per hectare, the additional water consumption would be at least 51 km^3 a year. Taking average efficiency of the irrigation systems as 0.6, one can obtain the amount of water used by new irrigated areas as 85 km^3 per year. If we add some unknown but considerable volume lost from the main irrigation canals we could come to the figure of water consumed by the new irrigation developments. Apparently, this figure is close to 100 km^3 a year. For comparison, before 1960 the average amount of water coming annually into the Aral Sea was about 55 km^3.

Thus even keeping in mind that the irrigation returned water coming back to rivers or canals are used again, no considerable inflow to the Aral Sea could be expected under the circumstances. In fact, the inflow went down to 11 km^3 by 1975, and to zero by 1980. In the 1980s the rivers did not reach the Aral Sea every year, and when it occurred the inflow did not exceed a few cubic kilometers. There was a similar decrease in the 1990s, with some flow into the sea during a few wet years. During the last three decades the precipitation in the basin was below average, so that about 20% of the inflow reduction was caused by the oscillations of climate while the main factor was the human activity in the basin. As a result, the Sea has been shrinking since the beginning of 1960s while the concentration of dissolved salts has been increasing.

Year	Water level m a.s.l.	Area 000 km^2	Volume km^3	Salt content g / l
1960	53.3	67.9	1,090	10.0
1965	52.5	63.9	1,030	10.5
1970	51.6	60.4	970	11.1
1975	49.4	57.2	840	13.7
1980	46.2	52.5	670	16.5
1985	42.0	44.4	470	23.5
1990	39.0	38.0	300	29.0

The former lake bottom is salty desert or solonchaks and serves as a source of salts spread out by wind. The rest of the Aral Sea is on the brink of being divided in a more deep western part and a more spacious shallow eastern part. The North-Eastern part, so called the Little Sea, is also practically separated.

Drastic changes have occurred in the hydrographic networks in the basin of the Aral Sea. A good part of the water infiltrated into the soil in the irrigation systems and conduits appears in many newly formed lakes and marshes situated in the desert. Sarykamysh Lake is the largest one collecting water north-west of the lower reach of Amudarya River. It has an area of 3,000 km^2 and a volume of 26 km^3. The dissolved salts content of its water is at present 12-13 g/l. Another lake, Arnasai, is correspondingly 1,800-2,400 km^2, 12-20 km^3 and 4-13 g/l. The Arnasai Lake collects water from the middle reach of the left bank of the Syrdarya River. In the irrigated areas a new, ample network of the irrigation and drainage canals has been formed. The level of ground water has gone up drastically in many places due to the seepage causing widespread waterlogging. There, the salinization of soils is a real and big problem. Along the rivers, the ground water level has gone down due to the drop of the river water levels. The deltas of the two principal rivers have completely changed their regime and mostly dried up. Consequently, the unique ecosystems of the river valleys and the deltas have disappeared, and many endemic species are under the threat of extinction.

Because of the agricultural returned waters, the salinity in the Syrdarya and Amudarya progressively increases downstream. In the lower reaches of Syrdarya the average salts content has changed from 0.8 g/l in 1960 to 2.8 g/l in 1985 and in Amudarya it has gone up to 1.7 g/l. Hence, though the rivers are currently the main source of water supply there, its quality does not meet the standards. In addition, the level of fertilizers application on the irrigated lands there exceeded 10-15 times the average for the whole of the USSR and a part of the fertilizers leaches down into the rivers. And even more, the level of pesticides application used to be the highest in the world with the subsequent implications to the water quality in both the rivers and the Aral Sea. In the lower reaches of Amudarya, 118,000 tonnes of pesticides were used during the last two decades, or about 10 kilograms per person per year.

The hydrological consequences (hydrographic features, water resources and their quality) of the development strategy adopted 30 years ago could have been predicted and many of them were. Many other, mostly environmental, effects were more difficult to foresee. An aboriginous, to large extent endemic, fish fauna was adapted to the brackish water of the Sea because the fish has evolved from the freshwater species. It could survive 13 g/l but the higher salinity has killed all the fish. The fishery as the main occupation of the population around the lake has gone, along with the annual catch of 44,000 tonnes of rare and valuable fish. People there have lost their main source of income.

Large changes have occurred in the environment. The direction, intensity and composition of the salts transport have modified considerably. The expansion of irrigation has led to the increase of the salts movement mostly with the drainage run-off. N. Glazovsky (1990) has calculated that the salts transport in the Aral Sea basin has increased about two times and is now 118 million tonnes a year. During the last three decades a huge amount of three billion tonnes of salts were removed within the basin. Of this volume, 60% have accumulated in the nearby ecosystems, in small new lakes and marshes, 27% have gone to the two large new lakes, Sarykamysh and Arnasai, and only 13% came to the Aral Sea. Moreover, the transport of sodium, chlorine, sulfate and magnesium has increased much more than that of the other main ions like calcium or carbonate.

Wind erosion of the former bottom of the Aral Sea has increased greatly, from 50 to 360% in different points around the lake. The salts transport goes along with it taking away between 1,000 and 10,000 t/km^2 per annum. For the whole former lake bottom it comes to 40-150 million tonnes a year (Glazovsky, 1990).

Transport of salts with the drainage water, the wind and the groundwater together with the raise of the groundwater level leads to the progressive salinization of soils. Soils with a medium or high degree of salinization occupy from 35 to 80% of the irrigated areas in the Central Asia. The land losses due to water management activities there have reached 1 million hectares (Rozanov, 1984).

The environmental degradation, namely unacceptable drinking water quality, high salt contents of the air and, apparently, high level of the pesticides residues in the agricultural produce make direct impacts on the state of human health in the Aral Sea basin. The worst situation is where the above factors make the most unfavorable combination, that is in the lower reaches of the two rivers and around the lake.

In the lower reaches of Syrdarya River the morbidity has increased 20 times over the last 20 years. The infant mortality in a number of districts exceeds 110 per 1000, that is three times more than the average for the former USSR and comparable with the figures for the least developed countries. The number of cancer cases in Karakalpakya (the lower reaches of Amudarya) is 7 times the all former USSR level. Over 90% of the population there suffer from anaemia, the number being 60 times more than the average for the USSR. In Karakalpakya 46% of women have genetic disorders of different kind and in its capital, Nukus, the breast milk of all the 35 mothers sampled was unsuitable for feeding. Clearly, the area close to the lake is in a state of environmental catastrophe and the whole of the Aral Sea basin is not much better. The water level of the Aral Sea is, therefore, an indicator of the difficult socio-economic situation in its whole basin.

But perhaps, the pitiful state of the human health and the environment is compensated by remarkable achievements in the economy of the region? Not at all. The plans to convert the whole of Central Asia into the blossoming garden have failed. On the contrary, the region has been converted into an area of cotton monoculture. The production quotas of cotton have kept increasing over the years, though the export expectations were not fulfilled and even some cotton of good quality had to be imported to mix with local cotton in order to produce textiles. Though it has not been made public yet, there are indications that the important user of the local cotton was the military-industrial complex producing a solid fuel for missiles, gunpowder and alike. As in many other regions and cases, the decades-long military orientation of the country has brought disaster to that potentially rich area.

The yields and the total harvest of cotton were rising through the 1960s and 1970s having almost doubled, but from 1980 they are in decline due to the salinization of soils and the monoculture. The quality of the cotton produced is in general low.

Pesticides indiscriminately used and spread from the air over both the fields and the villages have had pronounced impacts on the health of the population. The earnings from the cotton, if there were any, were not used wisely enough in the development of such social amenities as education and medical services. In addition, the students were forced to spend about two months collecting cotton at the expense of the quality of their education. Not much has changed there since the central Asian countries got their independence. Due to economic difficulties application of pesticides and fertilizers decreased, positively affecting the environmental quality.

The region has a very high rate of population, in the country but no new good lands supplied with enough water is available anymore. The development of irrigation could not absorb the growing population and unemployment is high. Tensions between the neighboring nations grow. In a number of places the national boundaries drawn in 1920s do not adequately reflect the realities, and any border change may lead to ethnic confrontations. The management of a large, multinational lake basin under these conditions is not a simple task.

And yet, it is obvious now that the development strategy of the Aral Sea basin adopted thirty years ago, was wrong. It has led to environmental catastrophe, maybe the largest in the world. The strategy has proved to be unsustainable. A new development strategy for the Aral Sea basin is urgently needed.

The most urgent problem is an expeditious improvement of the environment for the population of the Aral Sea basin, in particular in the areas situated close to the lake. The water supply there is of the highest priority. Major water conveying pipelines transporting water of acceptable quality have been built. About 300 desalinating installations have been put into operation. These actions have brought water supply for over half a million people. Some improvements were made in the health service of the population. The use of aircraft to spread the most toxic pesticides is more restrained than before. The immediate actions like those mentioned above can alleviate somehow the life of the people there but would not solve the crisis.

The crisis can be solved only if the strategy of development is changed. A comprehensive, long-term programme of the land-and-water resources management should be one of the cornerstones of the strategy. It should contain such elements as dropping low productivity lands from irrigation, increase of efficiency of the irrigation systems, drastic reduction of water applied for a unit of cropland, diversification of crops and liquidation of the cotton monoculture, optimal use of fertilizers and pesticides, transition to the integrated pest management systems.

However, the strategy must go well beyond the modern land-and-water management programme. It should go to the roots of the catastrophe addressing principal social and economic problems such as population control, a balanced ratio between the demand and supply of cotton, an appropriate structure for crop and livestock production, development of the agricultural extension services, conversion of industry from military production and considerable improvement of the social amenities including education at all levels and medical services. Much care should be devoted to cooperation among the nations of the region as the only basis for the lasting, sustainable development of the rich territory of Central Asia, and where the Aral Sea basin has the central position.

It has been mentioned above that the deterioration of the Aral Sea is an indicator of the deep troubles developed in its basin. A special programme to save the Aral Sea will not reach a desirable objective while a long-term sustainable development strategy for the basin, if successful, would bring as a side effect a stabilization and even a rise in the water level of the lake. An international cooperation among the states of the basin is necessary condition for the successful solution of the problem.

Currently, however, a sustainable development programme for the Central Asian States is nowhere in sight. The social situation continues to deteriorate, and the water level of the Aral Sea keeps dropping. To stabilize it at the present level, one needs an inflow of about 35 km^3 a year. It is possible and even economically feasible to save this amount of water by implementing a part of the land-and-water management programme mentioned above. To stop irrigating 15% of the lowest productivity lands would save about 20 km^3 of water. Control of the water seepage from the canals and more efficient watering of crops would bring at least 20 km^3 more. One has to emphasize, however, that the technological actions must go along with the careful analysis of the socio-economic implications of such actions.

A very complex environmental catastrophe occurred in the Aral Sea and its basin is the lesson to be learned world-wide.

Lake Balkhash is a large and shallow lake in the south-east of Kazakhstan at 340m a.s.l. Its area is around 18,000 square kilometers and the mean depth is only 6 meters. The western part of the lake where the main tributary, the Ili River, comes in, is with fresh water, while the eastern part has brackish water with salinity of about 5 g/l. The upper part of the Ili basin belongs to China.

In the middle reaches of the Ili River there is Kapchagai Dam with a water reservoir. Withdrawals for irrigation both in the Chinese and the Kazakh parts of the basin together with the evaporation losses from the water reservoir are important factors in the decrease of the water inflow into the lake. The consequences are similar to those for the Aral Sea, such as desiccation and deterioration of the river deltas, drop of the lake level and shrinkage of the lake area, increase of the water salinity, etc.. The environmental deterioration, though, has not progressed as far as that of the Aral Sea.

While the other large lakes discussed in this paper are situated at low altitude, the **Issyk-Kul** Lake is in Tian-Shan Mountains at about 1,600m a.s.l. and is surrounded by ice-capped ridges of 3,000m and more above the lake level. The water is brackish with salinity of about 6 g/l. Transparency of water is the highest measured in the USSR and its colour is an intense blue. There is no doubt that this very large lake (6,300 km^2) is one of the most beautiful in the world.

Variations of the water level of the lake depend, first of all, on the regime of precipitation on the basin and the lake. From 1910 to 1969 the lake level fell by 3.3 m though some smaller ups and downs have been observed during that time. From 1969 onwards, there was a continuation of the drop followed in the recent years by some increase of the water level. Human activity is developed mainly around the lake shore. The main consumer of water is irrigation which is developed in the Central and Western parts of the lake valley while the Eastern part has enough precipitation for rain-fed agriculture. It is doubtful that the withdrawals for irrigation play a considerable part in the regime of the lake.

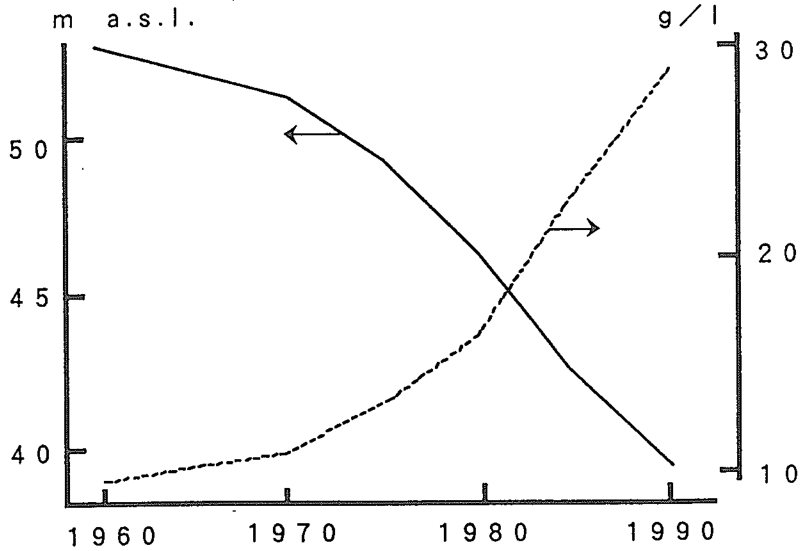

Fig. 4.1 Aral Sea - the Water level and Salinity

The main environmental problems are associated with somewhat chaotic development of the basin. Rapid expansion of tourism is not accompanied by proper sanitation facilities. Some industry and agricultural activities also increase the water pollution. The shame is that the lake was used for a number of years as a navy test area and, hence, it was forbidden to address properly the environmental issues there. In spite of a large water volume (1,700 km^3) the water pollution is spreading, being mainly in the coastal areas spoiling the beauty of the lake.

The Caspian Sea is the largest lake in the world. Its area is about 400,000 km^2, the volume of water is almost 80,000 cubic kilometers and the maximum depth exceeds 1,000 m. The water level is at an altitude of minus 26-28 meters. The basin of the Sea is 3.1 million km^2.

In the Caspian Sea basin there is the larger part of the population of Russia. Over half of the country's energy is produced there, as well as a considerable part of the industrial and agricultural production. The lake itself is a source of fish including such valuable species as sturgeon. The Caspian Sea is the main, almost exclusive producer of caviar in the world. The navigation over the Sea and its principal tributary, River Volga is quite developed. There are rich oil fields both beneath water and near the shores.

The Caspian Sea can be divided into three main parts. The deepest southern part contains two thirds of the Sea volume. The middle part has about one third and the volume of the northern part with the depths not exceeding 10-25 m is about 1% of the total volume. Salinity of water changes from 13-14 g/l in the South to 1-2 g/l in the North where the main tributaries, the Volga and Ural Rivers, come into the Sea. Due to the shallowness of the northern part, the oscillations of the Sea level cause noticeable changes in the position of the shores.

The oscillations of the water level of this gigantic closed lake are quite considerable. There is much evidence of the large water level fluctuations in the historic past. During the five decades from 1880 to 1930, the level went down by about half a meter. A very drastic drop in the water level occurred from 1932 to 1945, when it fell by 1.85m. This trend continued and by 1956, the water level dropped a half meter more. The area of the lake decreased by 37,000 km^2, mainly at the expense of the shallow northern part of the Sea. The pronounced changes in the configuration of the shores could be very visible even on small scale maps.

The drop in the water level brought many impacts on the economy and ecology. All ports had to be adjusted to the lower water level. The navigation canal in the Volga delta had to be dredged constantly. The fish spawning grounds reduced causing loss in the fish production. Salty deserts appeared in place of the lake bottom.

Between 1956 and 1978, the water level almost stabilized going down by about 0.3 m more and reaching a point below minus 28.5 m. All sectors of the economy adjusted to the new, low water level. There was, though, one major point of concern: a slight further drop of the water level by, say, 50-100 cm would dry out the main fish spawning grounds. That was the kind of a natural threshold below which a large and a valuable ecosystem of the Northern Caspian would virtually disappear.

The drastic drop of the water level was mainly ascribed to the expanding economic activities in the basin consuming ever more water. In 1973 the total water consumption in the basin was 29 km^3 a year or almost 10% of the total river run-off inflow and was undoubtedly to grow. It was believed that the regime of the water level and of the Caspian Sea water balance was practically completely caused by the economic activity in its basin (Shiklomanov, 1976). The forecasts gave a further considerable drop of the water level so that the Sea would be facing a major problem. Large-scale water transfers into the Caspian basin appeared among the main national water management plans (Golubev and Biswas, 1979).

However, the forecast proved to be wrong. Since the end of the 1970s the water level started to grow quickly exceeding the lowest level by about 1.5 meters. By 1996, the level was close to minus 26 m. Apparently, the main reason for the growth was improved water balance of the basin. The economy has to adjust again to the higher and still increasing water level. All the navigational facilities must be rearranged. Protection of the cities and other settlements are on the agenda as well as protection of railways and roads. Exploitation of the oil fields is also a problem.

Obviously, a stable water level of the Caspian Sea, no matter whether high or low, is the most convenient.

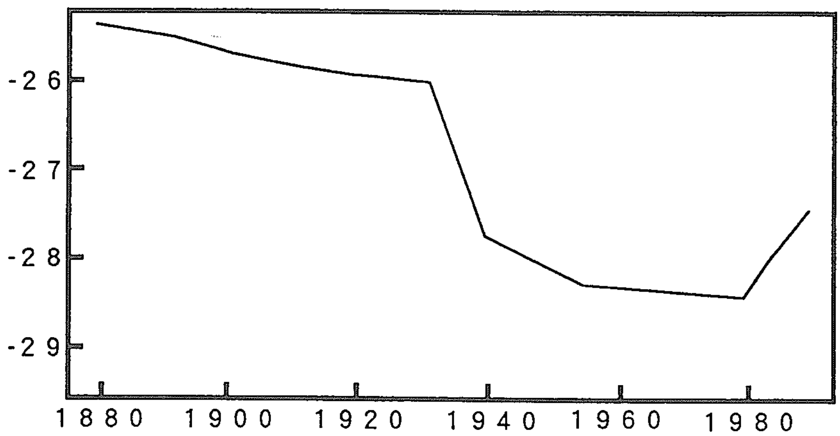

Fig. 4.2 Caspian Sea - the Water Level

Much field studies on the Caspian Sea, some of them quite detailed, have been done during the last few decades when the lake was in different stages of its evolution. The result of these studies are very valuable now: the Caspian, due to the considerable water level increase, can serve as a large scale model to understand the natural processes and implications of the world-wide sea level rise connected to climate change.

To sum up, the closed areas have special set up of environmental problems where changes in the lakes serve as a good indicator of the natural and socio-economic processes in the basin. However, due to the individuality of each lake and its basin the resultant problems are quite different from place to place. The study of the closed lakes and their basin in the world seems to be a promising area of further international research.

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CHAPTER 5

NATURAL HISTORY OF LAKE NASSER-NUBIA WITH SPECIAL REFERENCE TO ENVIRONMENTAL AND ECONOMIC QUESTIONS

B. Entz

5.1 INTRODUCTION

There were, about six to ten thousand years ago, basic changes in the climatic conditions of North Africa. The once green territory of the Sahara became dryer and dryer. The ancient inhabitants were pressed to move to the east, to the only area with permanent water supply, the valley of the Nile River. This green valley, particularly its northern most section (i.e. Egypt) became about 5,000 years ago, in the pharanoic times, with its dense population the cradle of human civilisation. (Rzóska, 1976).

Indeed the River Nile was then, and is now, the only source of water, a real "life artery" amidst a vast desert landscape. In Egypt, the "gift of the Nile" tillage became more and more widespread, first in the form of drawdown agriculture, and later by more and more developed irrigation systems.

To make irrigation easier and more effective, barrages have been constructed along the river, and the damned water was spread on the flat areas of the Nile valley. These activities together with fisheries assured the food supply for the population of the Nile valley during several millennia.

During this period the Nile flood, inundating and soaking year by year temporarily huge areas, setting there new mud layers, rich in nutrients, assured the continuous fertility of lands used for intensive agriculture, maintaining in the meantime the ecological balance of the soil.

From the beginning of the 20th century, basic changes occurred in the continental waters caused by expanding human activities. The immense growth of human population needed always more and more water for drinking purposes and for irrigation of new areas to obtain more food. For all these and several other purposes more energy supply was necessary.

To fulfill these requirements both in Egypt and in Sudan, all along the Nile River - based on ancient traditions - new dams have been constructed to store the water of the regular yearly Nile flood (as the old Aswan dam, the Sennar dam, the Roseires dam, the Gebel-Auliya dam etc.). These activities realised a quite important increase of arable land around the river. This is obvious by comparing data of the years 1920 and 1955 as follows:

Arable land surface in million Ha.

	Only drawdown agriculture	Land for perennial irrigation
1920	1.00	2.5
1955	0.43	3.75

Further needs for more arable land and more electric energy raised the issue to construct instead of more small periodical reservoirs, southwards of Aswan a huge man-made lake, named Nasser-Nubia Lake or High-Dam Lake (HD-Lake) with perennial storing capacity. According to this plan along the Egyptian Nile, beside irrigation of winter crops continuous irrigation could be assured during the summer months, to achieve more valuable summer crops too. Furthermore, an electric power plant with very high capacity could be constructed. This plan seemed more realistic because the water discharge of the Nile changes seasonally in a very high degree. So in normal years, during the flood (from the end of August until the beginning of December) the water discharge of the joint Nile (the River Nile below Wadi Halfa) is usually 700 x 10^6 m^3/day, while in other season (during low water) it does not exceed about 40 x 10^6 m^3/day. But if the monsoon rains are insufficient in the catchment area of the Blue Nile, the discharge might be reduced much below the amount mentioned (e.g. to 14 x 10^6 m^3/day in 1912/13) when the extremely reduced discharge attained only 42 km^3/yr.

On the other hand, in very rainy monsoon years, like in 1878/79, the discharge of the Nile at Wadi Halfa reached 151 km^3, with a daily maximum reaching 1666 x 10^6 m^3/day.

The new reservoir could regulate the flow of the river, keeping a normal discharge below the High Dam even in dry years, and by controlling high floods, avoiding any flood catastrophe between Aswan and the Nile Delta. Construction of the High Dam started in 1957. The river flow was first blocked in 1964, and the High Dam[(1)] outlet was completed in 1968, but the filling of the reservoir took more than 10 years, when in 1975 the probable working level was reached, at about 175 m a.s.l.. Though the dam is foreseen already with an overflowing outlet to divert water masses above 182 m a.s.l., to avoid catastrophes possibly occurring by extraordinary high floods (like that of the years 1878/79), a second outflow was built in the seventies in the Tushka area (Fig. 5.1) - about 200 km south of the Aswan - into the New Valley, a valley parallel to the Nile Valley in the Western Desert, with practically unlimited filling capacity, to drain the surplus water masses above 180 m level.

[(1)]The Aswan High Dam is a rockfilled dam. It emerges 111m above the Nile bed. It is at its bottom 980m and at its top 40m wide. Its length is 3.6 km. The water is diverted to flow through a new water passage, with six main tunnels. Each tunnel has two outlet branches feeding 12 turbines, having together a capacity of 2.1 x 10^6 Kw. The produced electricity, because of the desert conditions (extremely dry air) with minimal loss, can be spread all over Egypt.

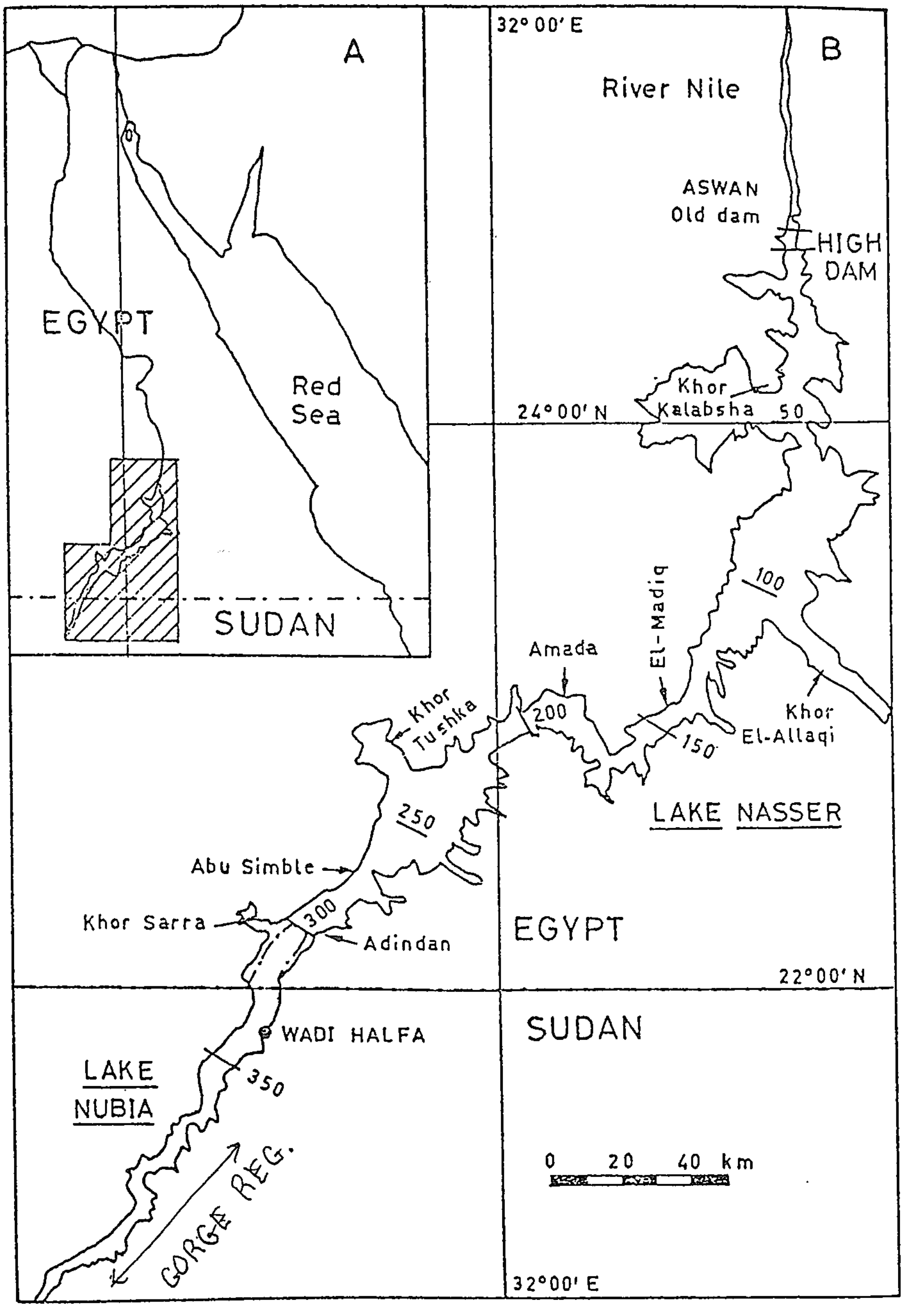

Fig. 5.1 A - Site of Aswan High Dam reservoir in Egypt and Sudan. B - Lake Nasser and Lake Nubia.

5.2 LOCATION, MORPHOLOGY AND HYDROLOGY OF THE HIGH-DAM LAKE

The lake consists of two parts. The northern (Egyptian) part is called Lake Nasser, while its southern part (the Sudanese lake area) is called Lake Nubia. (Fig. 5.1)

The whole reservoir when full, extends along the Nile Valley from Aswan to the Dal Cataract, i.e. between 23°58' and 20°27' N latitude and from 30°35' to 33°15' E longitude. At the time of its construction it was the third greatest man-made lake of Africa and the fifth in the world.

It is unique in its performance, because it is created amidst a pure desert landscape, where (in Aswan in the north as well as in Wadi Halfa in the south) the yearly mean precipitation does not surpass 4 mm annually. In addition, precipitation - if present - is very irregular. Sometimes there is a thunderstorm with 100 mm precipitation and thereafter there is not a single drop of rain perhaps for 20 or even 25 years.

Some morphometric data of the reservoir are summarised in Table 5.1 and 5.2 and Fig. 5.2 and 5.3a and 5.3b.

Table 5.1

	Lake Nasser		Lake Nasser-Nubia (HD-Lake)	
Water level (m)	160	180	160	180
Length (km)	231.8	291.8	430.0	495.8
Surface area (km^2)	2585	5248	3087	6287
Volume (km^3)	55.6	132.5	65.9	156.9
Shoreline (km)	5400	7200	6000	9300
Mean width (km)	8.9	18.0	7.1	12.5
Mean depth (m)	21.5	25.2	21.6	25.2
Maximal depth (m)	110	130	110	130

For more details see Table 5.2, 5.3a, 5.3b.

The number of remarkable side arms of the lake - called khors, i.e. flooded wadies - is about 100, with a total length of cca. 3,000 km. The lake has in this way an extremely ramified peculiar dendritic form (see Fig. 5.1) particularly in its Egyptian part, with a very high shoreline development value (33.1 = D_L according to Hutchinson). The flooded Nile Valley, as well as the khors have a "U" shaped form, with usually steeper slopes on the more rocky or stony mountainous eastern shore than on the flatter, more open, wider, often sandy western shore. (Photos 5.1 and 5.2).

The ancient river bed and its former cultivated edges form all over the lake the deepest areas of the reservoirs. The deepest sites are in front of the High Dam (110 to 130 m). From the High Dam the depth of the old river bed is decreasing gradually to Wadi Halfa (65-85 m) and becomes very shallow around the former 2nd Cataract (at present probably only 20 to 25 m deep), but shows further to the south in narrow gorge areas again some deep sites (e.g. at Duwishat 70m).

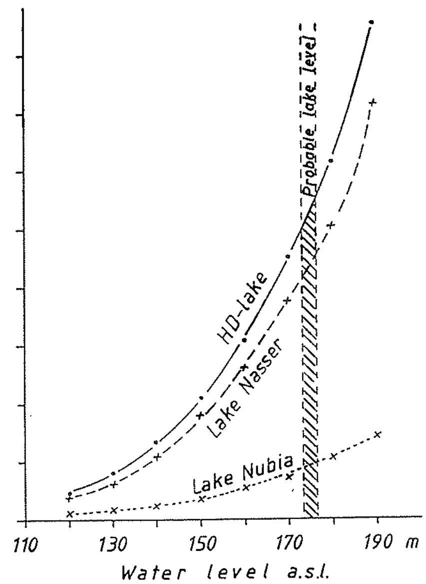

Fig. 5.2 Surface of HD-Lake

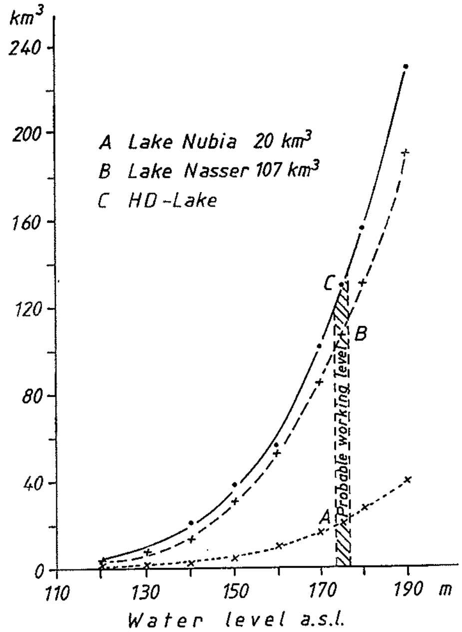

Fig. 5.3 Volume of HD-Lake

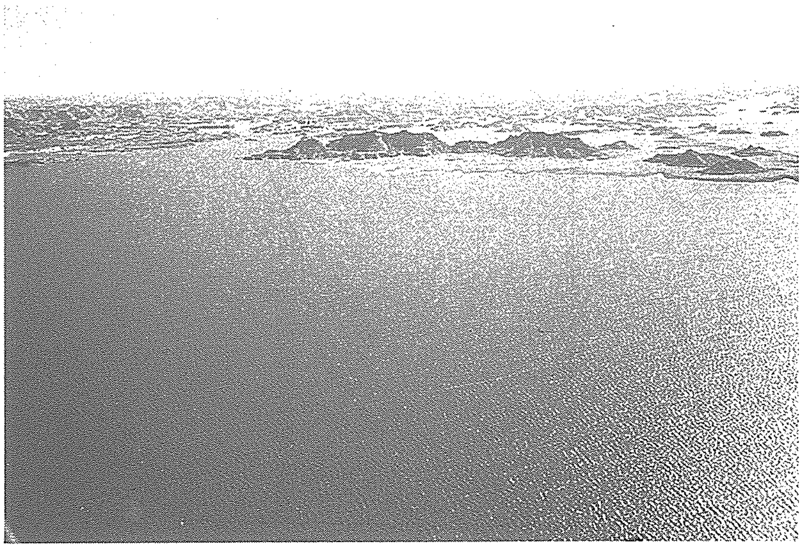

Photo 5.1 Bare rocks and sandy beaches in the area of Ibrim. (Lake Nasser, January 1974) (Entz 1979)

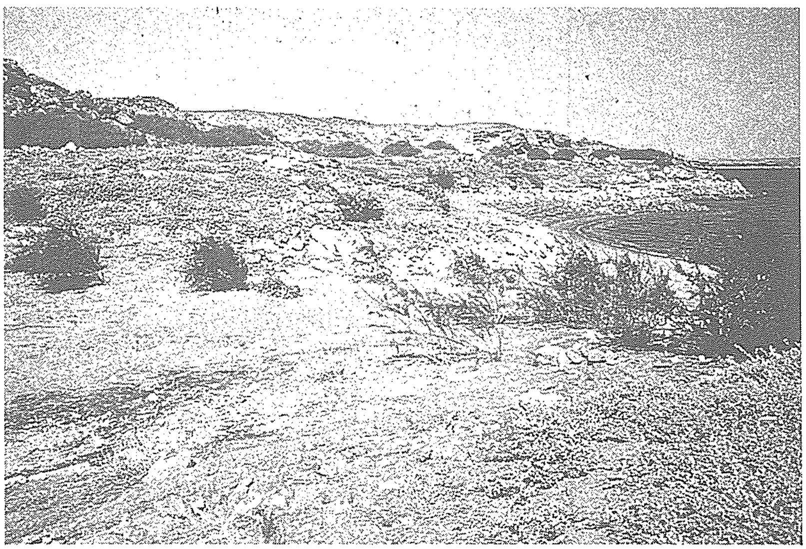

Photo 5.2 Salt crust caused by capillarity. Lower white crust, pure NaCl. Upper dark cover, mixture of hygroscopic salt. (June 1973) (Entz 1979)

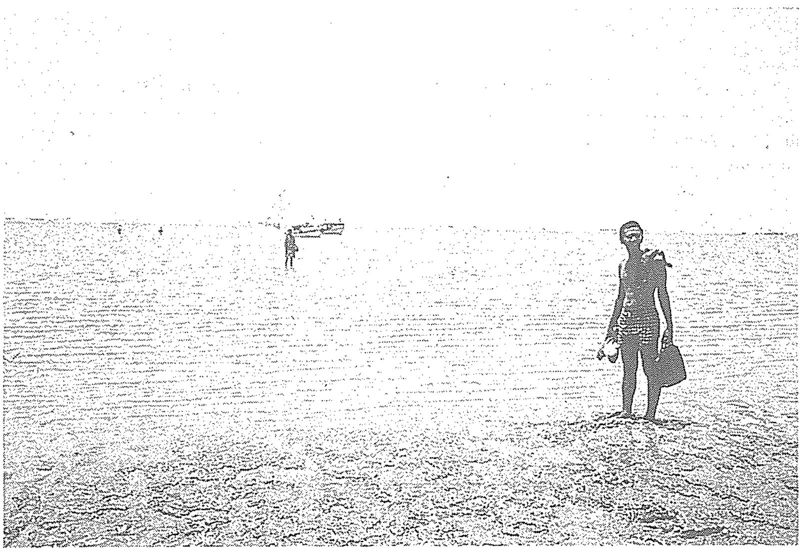

Photo 5.3 Freshly deposited silt near Wadi Halfa. (Lake Nubia, September 1973) (Entz 1979)

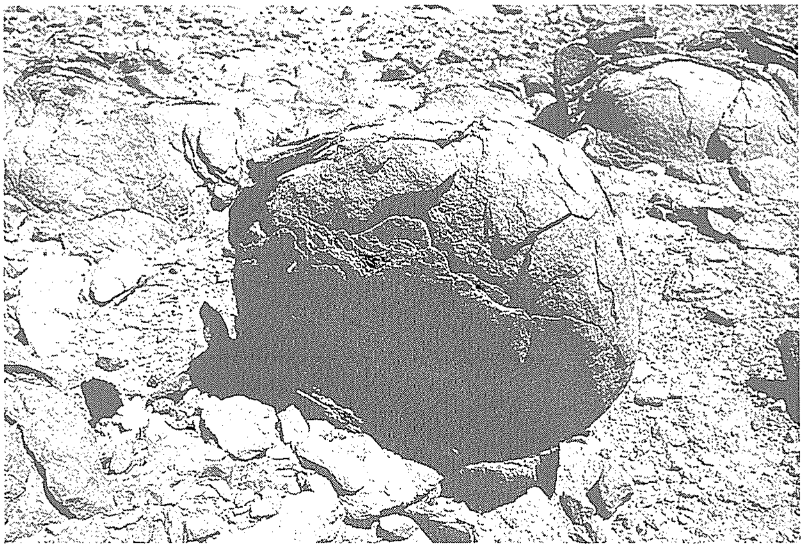

Photo 5.4 Rounded granitic rock with shelled structure due to temperature-erosion under desertic conditions.

Table 5.2 Morphologic and limnologic data of High Dam Lake (HD-Lake) HD-Lake=Lake Nasser (Egypt) + Lake Nubia (Sudan)

Lake levels a.s.l. ms	Surface (km^2) See Fig.5.2			Volume (km^3) See Fig.5.3		
	Nasser	Nubia	HD-Lake	Nasser	Nubia	HD-Lake
120	393	39	451	3.9	0.3	4.2
130	630	146	723	9.0	1.3	10.3
140	1095	229	1324	17.6	3.2	20.8
150	1744	350	2094	31.9	5.8	37.7
160	2585	502	3087	53.5	10.2	63.7
170	3772	724	4496	85.3	16.6	101.9
175	4260	875	5250	107.0	20.0	127.0
180	5248	1039	6287	130.2	26.9	157.1
(190)	7140	1377	8516	191.9	39.1	231.0
Surface		between ms		Volume between levels		
120-130	234	88	322	5.1	1.0	6.1
130-140	468	83	551	8.6	1.8	10.4
140-150	650	120	770	14.2	2.8	17.0
150-160	841	152	993	22.0	3.9	25.9
160-170	1187	222	1409	31.7	6.5	38.2
170-180	1476	315	1791	45.0	10.3	55.3
(180-190)	1892	338	2230	61.7	12.2	73.9

Table 5.3a Hydrologic data about HD-Lake with special attention to agricultural aspect. HD-Lake=Lake Nasser (Egypt) + Lake Nubia (Sudan)

	Evaporation at different lake levels taking 86 km^3/yr mean water supply			Water outflow at Aswan (HD)		Fluctuation of lake level
Lake level (m)	Nasser (km^3/yr)	Nubia (km^3/yr)	HD-Lake (km^3/yr)	(m^3/sec)	(km^3/yr)	(m)
120	1.1	0.1	1.2	2670	84	19
130	1.9	0.4	2.3	2670	84	16
140	3.3	0.6	3.9	2600	82	14
150	5.2	0.9	6.1	2540	80	11
160	7.8	1.4	9.2	2440	76.8	9
170	11.3	2.1	13.4	2300	72.4	6.3
175[(1)]	13.7	2.8	16.5	2200	70	5
180	15.7	3.2	18.9	2120	67	4
(190)	21.4	4.8	26.2	--	--	3.2[(2)]

Table 5.3b Arable land around Lake Nasser-Nubia at different water levels. See Fig. 5.14.

Lake level (m)	Arable land for drawdown cultivation taking 5 m lake level fluctuation into consideration km². Nasser(2)	Nubia(3)	HD-Lake	Lake level (m)	Arable land for irrigation (shore area till 10 m above highest lake level) Nasser	Nubia	HD-Lake
125	117	41	161	130	350	86	436
135	234	44	278	140	558	102	660
145	325	60	385	150	745	136	881
155	420	76	496	160	1013	188	1201
165	593	111	704	170	1333	269	1600
175	738	157	895	180	1500	300	1800
185	946	169	1115	190	1684	326	2010

(1) Probable working level of reservoir.
(2) Value at 183m.
(3) Above 155 m lake level without mud sedimentation
(4) At any lake level with mud sedimentation

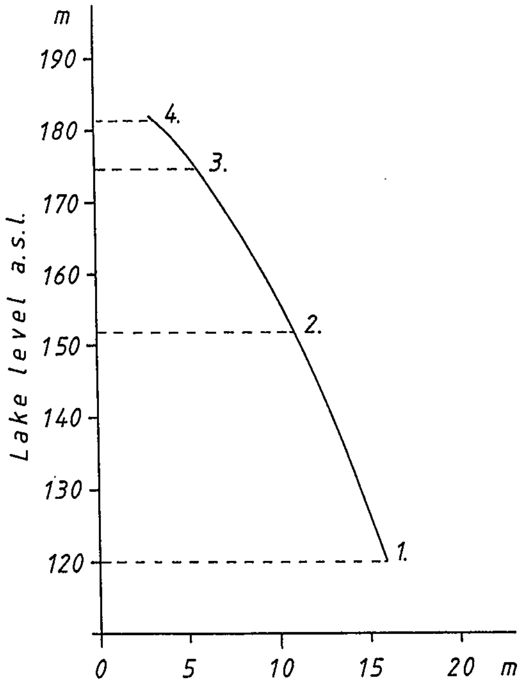

Fig. 5.4 Difference of High- and Low-water.

5.3 SOME ASPECTS ABOUT THE UNIQUE PERFORMANCE OF THE HIGH-DAM-LAKE

The conditions in and around the HD-Lake are in certain respects more simple than in other reservoirs. Let us consider some of these:

1. The lake has only one source of water - the Nile River - because it has no other tributaries. Precipitation is practically nil.

2. Clouds are very rare, so there is full sunshine without any hindrance all year round.

3. The environment of the lake was at the time of its formation and its filling stage pure desert, without vegetation on its shores and without submerged macrophytes.

4. Terrestrial animal life around the lake was, at the time of its formation, negligible.

5. The previous human population was re-settled and so absent from the area.

6. Contamination coming from the shore was accordingly not worth mentioning.

7. Instead of the previous riverine conditions lacustrine conditions were formed and spread continuously from the north towards the south during the filling process, until the final working level (175 m a.s.l.) was reached in about 11 years (1965-1975).

8. There is a regular annual rhythmic fluctuation of the lake level caused by the famous Nile flood.

9. The daily range of the open water temperature is not wide, in fact almost negligible.

10. The seasonal range of the open water temperature at the surface is restricted, ranging between 15 and 30°C, i.e. less than usual ranges in temperate lakes.

11. The lake area is quite windy. Prevailing are the northerly winds, usually with 3 to 5 m/sec, but often with 19 to 21 m/sec speed, having important effect on the hydrological regime (Fig. 5.5.).

12. Lake Nasser-Nubia is a monomictic, stratified sub-tropic lake with riverine, semi-riverine and typical lacustrine sections.

13. The flood water is much more turbid than the low water, and carries into the southern areas of Lake Nubia a heavy load of silt and sand, up to 8 g/l or more. (Fig. 5.6). The huge amounts of silt are in the first decades of the High-Dam-Lake mainly settled in the wide areas of Lake Nubia (± 0.1 km^3/yr).

14. Life conditions in and around the lake are strictly connected with different - partly already mentioned - abiotic and biotic factors as temperature, sunshine, wind, air humidity, depth of the water, currents, the Nile flood etc..

15. All these led to exciting changes of the flora and fauna during the filling stage, in the water and its immediate desertic environment, and made finally the utilization of this unique landscape in favour of the surrounding countries possible.

These circumstances gave the motivation for detailed studies supported by UNDP and FAO, and the Egyptian government from 1968 through to 1974. These studies gave, beside their great economic importance, the opportunity to follow up step by step the different lake phenomena accompanying the filling process of the lake, and to handle all these events as a large scale, very unique and peculiar scientific experiment.

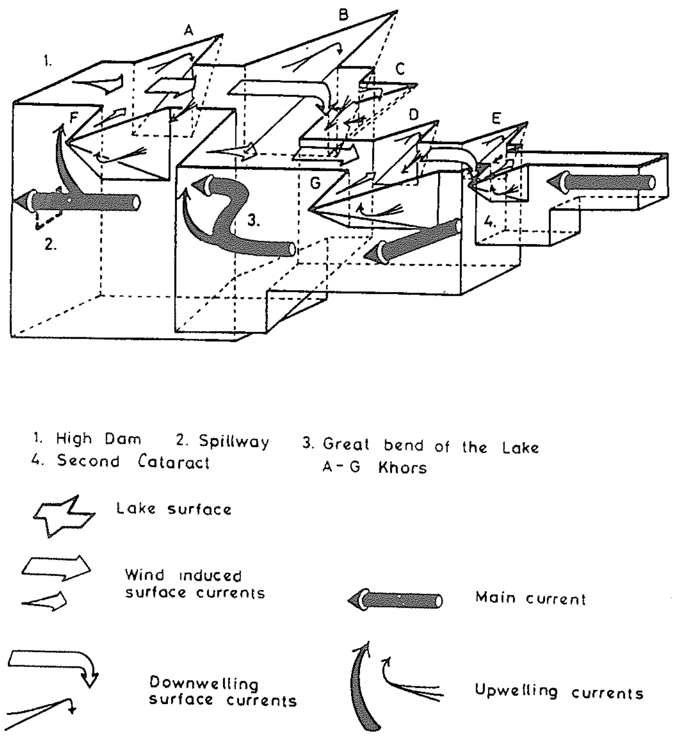

Fig. 5.5 Schematic representation of currents in Lake Nasser and Lake Nubia.

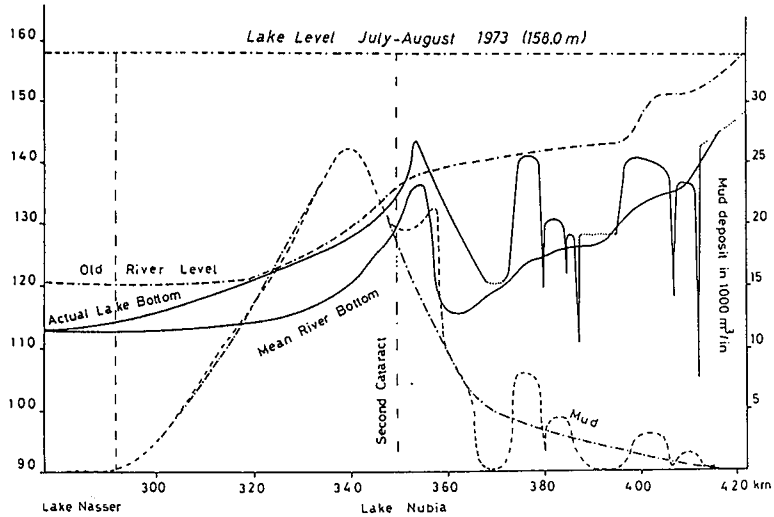

Fig. 5.6 Lake levels

Photo 5.5 Recently sedi-nented mud on pure desert sand at Lake Nubia. The dried columns of mud are 2 m high being partly washed with the wave action. (flood season 1972-73) (Entz 1979)

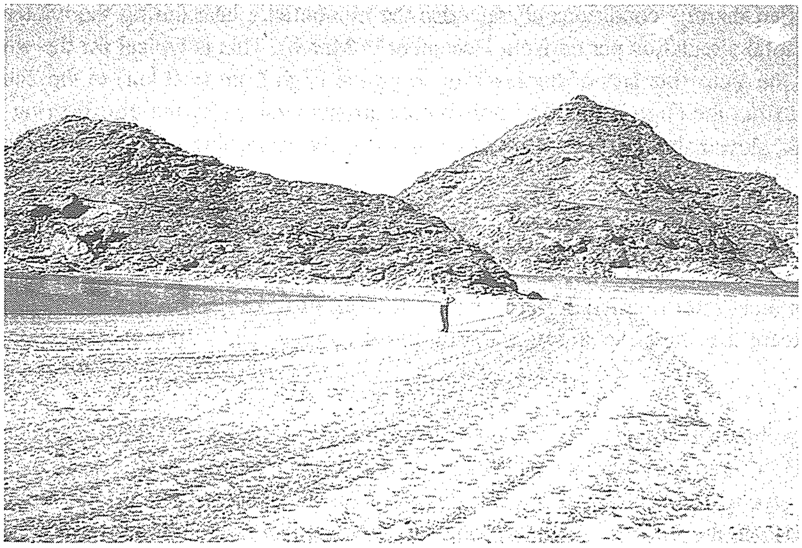

Photo 5.6 First seedlings of *Glinus lotoides* arranged in parallel rows by wave action during decreasing water level. (January 1970) (Entz 1979)

Photo 5.7 Bushy vegetation in Khor-el Birba about 5 km from the main Nile Valley near Aswan, at low water level in 1973. (*Tamarix nilotica, Rumex dentata* and *Glinus lotoides*) (Entz 1979)

5.4 TEMPERATURE CONDITIONS

Unstratified thermal conditions characterise the monomictic lake during the winter overturn (i.e. the total circulation period from December to March). This is typical for the whole water mass of the lacustrine part of the reservoir from the High Dam (= 0 km) to the 2nd Cataract (365 km from the High Dam). The horizontal currents induced by the transflowing Nile here are weak, slower than 10 resp. 15 cm/sec, but usually decreasing to 5 cm/sec or less by the HD.

During this period the water temperature (15 to 18°C) is approaching that of the ambient air temperature with about 45% air humidity. A similar situation could be observed in the southern most semi-riverine or pure riverine sections of Lake Nubia (365 to 495 km from the HD), except that there the strong, often turbulent currents, show speeds between 20 and 100 dm/sec.

From April the situation is quite different. The air becomes hotter and dryer with temperatures around 35°C, and peak with 48°C and air humidity often less than 20%. Due to these, a long-lasting strong thermal stratification develops in the lacustrine sections from April to September (in the southern sections) and even to November in the northern parts. Considering these conditions the following could be established:

1. From April stable stratified conditions dominated all over the Lake Nasser and in the northern part of Lake Nubia to the 2nd Cataract. The metalimnion was formed 10 to 15 m deep in the north and deeper (20 to 50 m) in the south. The temperature of the epilimnion rose up to 26-31°C, exceptionally to 34°C. These relatively low temperatures, as compared with the much higher 35 to 48°C summer temperatures of the air, are probably due to the very strong evaporation caused by the high ambient temperature, the extremely low relative humidity (down to 24-27% or even less) and the frequent strong winds. The hypolimnion keeps cold water (15 to 20°C) all over the stratification period.

2. South of the second Cataract, semi-riverine or even riverine conditions prevail, where frequently turbulent currents occur (speeds up to 100 cm/sec), so long-lasting stratification cannot develop there. Accordingly the temperature in the section (the so-called "Gorge-region") are similar in all depths of the water mass and correspond to those of the epilimnion in the lacustrine sections (26 to 31°C).

3. The destruction of the stratified conditions (summer stagnation) is influenced by two main factors:

   The first of them is the arrival of the usual Nile flood. The decisive effect of the flood water may be explained by its overwhelming amount, by its specific weight, caused by its lower temperature together with its high suspended silt content, and its stirring up effect, intruding into the wide areas of Lake Nubia in front of the 2nd Cataract with inertia.

During this event the flood water replaces the previous stratified transparent water masses in all depths, including those of the warm epilimnion and the cool hypolimnion. This activity is progressing towards the north and reaches the central region of Lake Nasser (120 to 180 km from the High Dam) by October and November.

The second factor responsible for the destruction of the stratification is the decreasing ambient temperature. This is the main factor causing the break down of stratified conditions in the northern sections of Lake Nasser, extending from the High Dam to Allaqi (0 to 120 km from the HD) in November and December.

Both factors may affect the end of stratified degrees, particularly in the central part of the lake, depending on the strength of the flood and the progress of the cooling down of the ambient temperature, differing in the course of the years (Fig. 5.7 and 5.11, Latif 1983).

4. From 1970 to 1974, it could be observed that the volume of permanent cold water (temperatures below 20°C) during summer stratification (i.e. the volume of the hypolimnion *sensu stricto*) was increasing. This covered in 1970 only a water mass of 0.02 km^3, in 1971, about 0.3 km^3, in 1972 and 1973, 6 to 7 km^3 and in 1974, more than 10 km^3. This tendency possibly continued in the following years. Accordingly the summer stability values, calculated from 0 to 40 m depth, increased from 157 mkg/m^2 in 1970, to 271 mkg/m^2 in 1974 (calculated after Ruttner 1953).

   This change is in agreement with the decreasing winter temperature minima of the water as 18.5°C in 1970, and 15.9°C in 1974. A further cooling down of the hypolimnion can be suggested but this process is limited by the winter mean minima of the ambient temperature. So until 1983 water temperatures below 15°C were not recorded in the open water and temperatures below 14°C are improbable, even in the future (Latif 1983).

5. Circadian temperature changes in the open water are negligible. Some restricted changes of this kind appeared in the littoral zone in very shallow water still not surpassing 4 to 6°C a day.

   The adjacent wet belt on flat sandy shores (4 to 6 m wide) showed higher but similarly moderate circadian temperature change, not surpassing 15°C a day. It is worth mentioning that the lowest temperatures could be measured here, sinking down to 10°C, the lowest temperature ever measured in the lake areas during our studies from 1970 to 1974, due to very strong evaporation (yearly mean value 3000 mm). This wet belt was after the first inundation on both sandy and rocky beaches during the filling process of the reservoir, usually covered all along the shore of the lake by an obvious salt crust. This crust came into being by elution followed by crystallization of soluble salts, previously hidden in the bottom, and raised by capillarity above the existing water level. This strange phenomenon could happen only under pure desertic conditions, showing extraordinary strong evaporation during the filling stage of the lake (1964-75). The lower zone of this salty belt contained white coloured crystals of almost pure NaCl, while the upper zone was transparent like glass (i.e. colourless), and was composed by very hygroscopic salts (Mg, Ca and K salts of marine origin). In the course of the years after several inundations and desiccations this crust became weaker and finally was washed away by wave action at raising water.

An almost stupefying change of temperature on the soil could be observed already at about 6 m from the edge of the water, immediately at the border of wet and dry sand within a distance less than 1 m. The temperature, as a result of undisturbed sunshine in the dry sand, rose abruptly and reached at noon in winter by ± 45% air humidity 35 to 42°C showing in bare sand a circadian range of 30 to 33°C. The surface temperature ascended further in summer by 24 to 30% air humidity up to 60-66°C, or even higher (i.e. in black sand). (Photo 5.4.)

The circadian variation of the temperature in the sand was the strongest at the surface (reaching sometimes 33°C). This range was weaker about 5 cm under the surface and still weaker in 10 cm depth (± 10°C). There could be no remarkable change of temperature recorded 100 cm under the surface. There the temperature was about 30°C all year round, corresponding the yearly mean temperature of the area. All the observations and measurements mentioned above have been performed in the Khor el Birba (= Khor el Ramla) area, about 9 km south of the High Dam.

It seems important to take these results, regarding the temperature conditions of the aquatic and the terrestrial environment, into consideration by human activities in the field of fisheries, agriculture or animal husbandry.

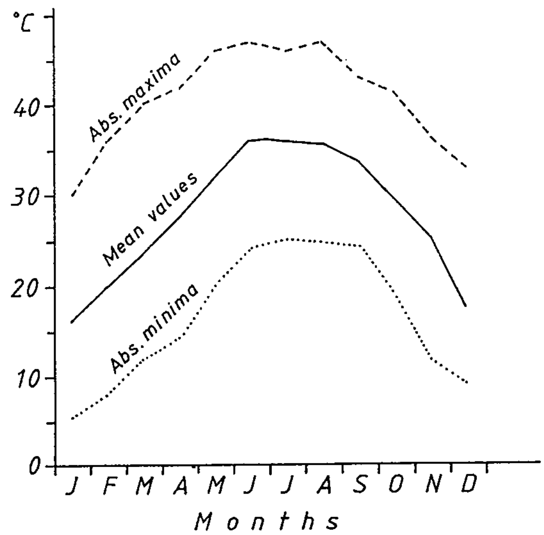

Fig. 5.7 Air temperatures of Aswan (1966 - 1969)

5.5 OXYGEN CONDITIONS

The oxygen saturation of the water reflects the influence of four important factors:

1. The temperature regime;
2. The effect of wind;
3. Aquatic life conditions; and
4. The desert surroundings.

During the total circulation period in winter time, with almost equal temperatures from the surface to the bottom, the total water mass is oxygenated practically all over the lake area (saturation values from 60 to 120%).

From April under stratified conditions, the epilimnion shows usually O_2 supersaturation (up to 160 or 200%), in the lacustrine part of the HD Lake. This is mainly due to remarkable algal photosynthesis. On the contrary by the same time in the dark stagnant water masses of the hypolimnion the oxygen saturation gradually decreases, caused by opposite biological processes, as respiration of animals, bacterial decomposition etc.. Finally, there is a lack of oxygen at the bottom and the deep water layers for five to seven months. Under stratification beside a thermocline, a characteristic chemocline is formed with decreasing O_2, pH, etc.. Stratified conditions are the most durable in the northern very deep sections of Lake Nasser and the shortest near Wadi Halfa from April, sometimes only until August. Stratification is absent practically all year round in the riverine and semi-riverine sections of Lake Nubia - the so called Gorge-region.

Accordingly the colour of the bottom deposits is brown in the south (oxygenated mud), but changes gradually towards black, following the lake towards the north. Finally, it is pure black in front of the High Dam. Here even the spilled water has sometimes a bad odour caused by H_2S, if the water is coming from the hypolimnion. The black colour of the deposits comes from its FeS content.

These phenomena became always more distinct in the years from 1970 to 1974, changing the life conditions in the deep water zone and the bottom habitats basically.

5.6 SILT CONTENT AND CONDUCTIVITY OF THE WATER OF THE LAKE WITH SPECIAL REFERENCE TO THE YEARLY FLOOD AND SEDIMENTATION

The water output of the Nile together with its mud content played, as already mentioned, connected with the famous Nile-flood, an invaluably important role in the history of the Nile.

As widely known, the Nile carries a heavy load of mud, an assumed amount of 134 million tons/year (= 0.1 km^3/yr), consisting of a mixture of sand, silt and clay, with a remarkable organic matter content (Photo 5.5, 5.6 and 5.7). Most of the mud was sedimented all along the Nile valley before 1964, the date of closure of the High Dam, from the 2nd Cataract till the Nile-delta, assuring the fertility of the Nile Valley for thousands of years. Since then the situation has changed fundamentally. During the first years of existence of Lake Nasser (1964 to 1967), caused by the still remarkable current, the suspended mud was "flushed" through the lake and even through the spillway. But after reaching 150-155 m lake level in 1967-68, the current within the lake was reduced so much that a strong sedimentation started within the lake itself.

The southern part of the reservoir Lake Nubia showed different conditions. There are in the so called "Gorge region" (between the Dal Cataract and the previous 2nd Cataract, i.e. 350 to 496 km from the High Dam) almost pure riverine conditions. The water in this section is always turbid. The speed of the current may reach more than 100 cm/sec there. The flood water carries tremendous amounts of suspended silt there, particularly during the first day of its arrival.

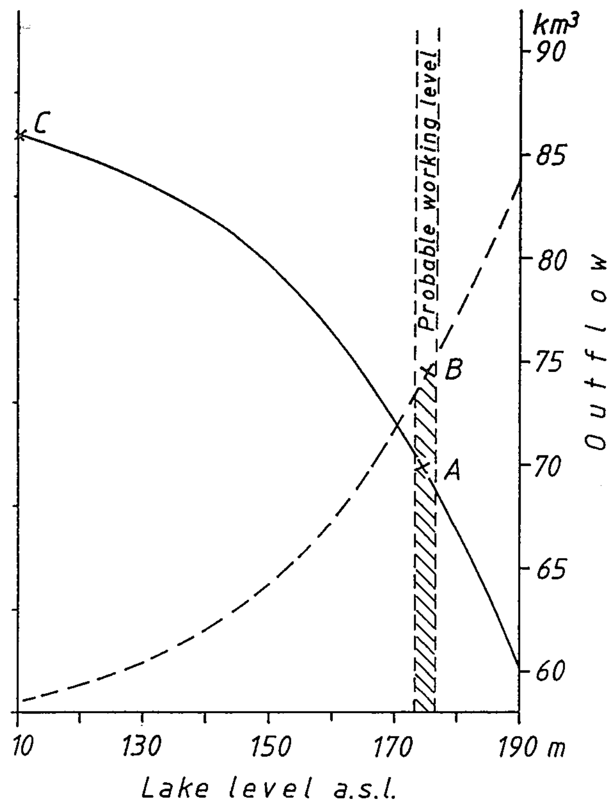

Fig. 5.8 Water regime of HD-Lake

Some sedimentation of suspended silt has already been recorded also in this section, during the high water period in first flooded but after the recession of the water level again uncovered localities. Along these places very thin intermittent layers (± 1 mm thick) of sand, silt and clay could be observed showing the changing composition of the actually present suspended silt of the progressing flood water. From these layers, after drying by wind induced abrasion 1 to 5 cm high tiny sand hills, "mini-mountains" were formed, resembling very much the huge existing sandstone mountains of the surroundings. In other corners (e.g. bays) of the Gorge-region thick mud sediments appeared within one flood period on desertic sandy shores, just beside the streaming flood water. The sedimented mud became gradually dry at the top but for a long time viscous at the bottom, forming 1 to 2 m high polygonal columns. These columns were later attacked by wind and rising lake level, collapsed and were washed away (see Photo 5.5).

In certain localities the new sediments formed in decreasing flood water parallel to the shore, slightly emerged low dams separating the lotic and limnetic water masses, indicating probably the shore of the future water-way in times to come when due to sedimentation the filling process of this section of the lake by mud will be completed.

In 1973, the suspended silt content of the progressing flood water reached, according to our own measurements, 8000 mg/1 (or even more), but decreased soon within one week to about 1000 mg/l, by all means still not a negligible amount (Entz 1974).

At the end of the gorge section arriving to the wide confluence area near Amka, just above the old 2nd Cataract (about 360 km from the HD), the speed of the current was reduced at once to about 10 cm/sec. An almost incredible sedimentation of suspended matter started there forming a more than 1 m thick new sediment layer year by year, like an underwater delta formation (Fig. 5.6 and 5.9.)

An estimated 9% of the suspended silt was sedimented within the gorge area (365 to 496 km from the HD), followed by 90% in the wide area of Lake Nubia (300 to 365 km from the HD.)

Looking from the air it becomes evident that the turbid brownish-greyish flood water practically pushes the old, green, transparent water mass towards the north. In the meantime a sharp demarcation line appears between the two kinds of water. Further to the north, due to progressing sedimentation, the flood water becomes clearer and the colour differences between the old and new water masses turn pale and finally disappear. Although during the first decade of the formed new reservoir the bulk of the sedimentation process happened almost exclusively within Lake Nubia, due to the colour differences mentioned above, the progress of the flood water could be observed by the naked eye to the center of Lake Nasser (to about 170 km from the HD). Only conductivity measurements allowed us to follow the progress of the flood water further down to the High Dam. The flood water has namely lower conductivity than the old low water of the lake (190 to 220 μS and 240 to 290 μS respectively. Fig. 5.11). During 1973 the flood water started from Melik el Nasser at the beginning of August and reached the High Dam area in December to early January, by 160 m lake level. This time interval is assumed to be still longer in the following years at 175 m working water level.

The inorganic silt content of Lake Nasser was constantly very low, particularly in its northern sections. The suspended silt together with the phytoplankton and the inborn detritus usually does not surpass 10 mg/l there. Sedimentation of silt in Lake Nasser is though increasing, particularly near the Sudanese border, but is at present negligible. Evidently the turbines of the High Dam are at present definitely not affected by siltation, and this situation will still remain most probably for several centuries.

The Nile mud will yet fill the whole reservoir theoretically within about 1700 years. Though flushing of mud deposits through the spillways caused by the shrinking volume of the lake due to mud deposition, may happen some centuries earlier.

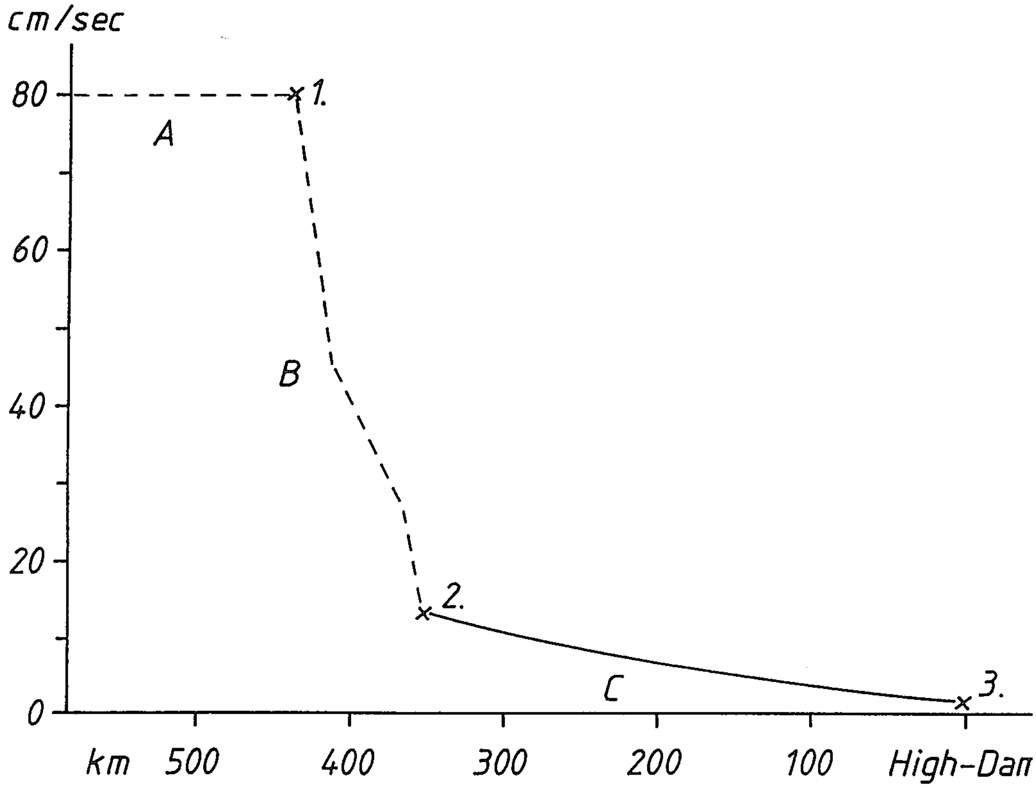

Fig. 5.9 Speed of current in cm/sec at different distances from the High-Dam (kms). Low water August 1973.

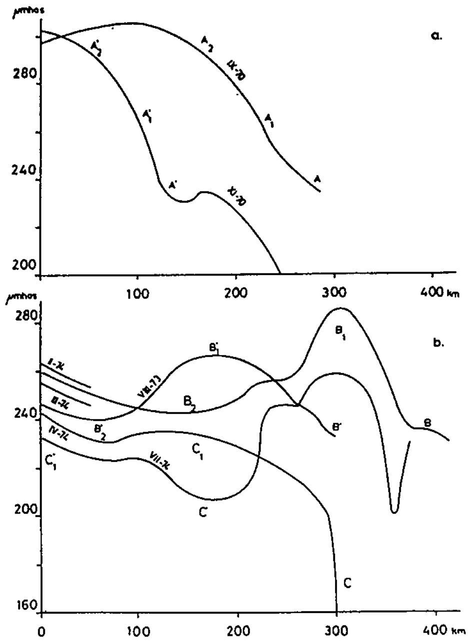

Fig. 5.10 Decreasing conductivity of water in the habitat of chironomids from 270 - 300 µMhos within the old water to 190 - 240 µMhos in the flood water.

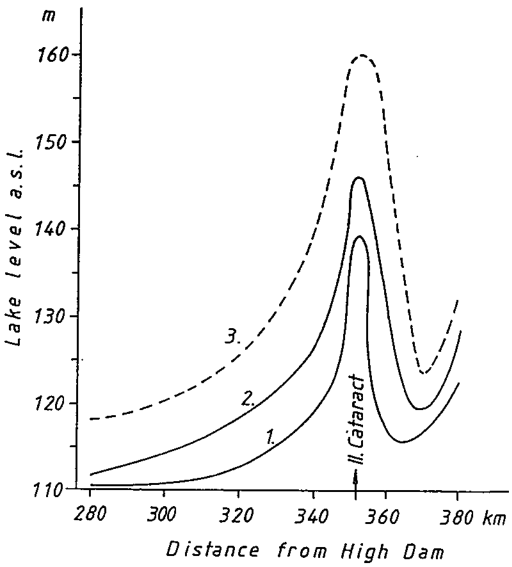

Fig. 5.11 Sedimentation around the 2nd Cataract

5.7 LIGHT CONDITIONS. THE EFFECT OF SILT, PHYTOPLANKTON AND WIND ON THE TRANSPARENCY OF THE WATER.

The transparency of the High Dam Lake depends on three main factors. The first is the amount and the dispersion of suspended matter in the water as silt and detritus. The second is the quality and quantity of phytoplankton, and the third is the wind.

Abioseston or silt is the dominant factor regulating the light conditions all year round in the gorge region of Lake Nubia. Here the transparency measured with the Secchi-disc (mostly indicated as Secchi-transparency) is very low. Usually it does not surpass 20 or 30 cm. In fact when the flood water arrives it can be as low as 5 cm. During the flood season the silt content determines the transparency within the semi-riverine section of Lake Nubia and the southern sections of Lake Nasser with obvious turbid water (transparency usually ranging between 30 and 70 cm).

On the contrary, under lacustrine conditions, in the clear, green water of the low water period, the transparency is mostly higher in the open water areas of Lake Nubia and Lake Nasser. As a regulating factor here a more important role is played by the phytoplankton. The transparency values in the lacustrine sections in the winter months are much higher, ranging from 100 to 300 cm. This is in agreement with the low phytoplankton development. All these data are based on our studies performed during the years 1969 to 1974.

As a third factor wind plays also an important role. Long lasting strong northerly winds play in Lake Nasser a very peculiar role. This is most evident near the High Dam. In this wide open area of the lake, extending from the High Dam almost 200 km straight from north to south. Here the surface water masses, including their remarkable phytoplankton content, are frequently blown southwards. Consequently beside the High Dam strong upwelling takes place (Fig. 5.5.). The upwelling water comes from the hypolimnion, being almost completely without suspended silt and plankton organisms. Accordingly in the very clear water exceptional high transparency values could be detected (up to 700 cm or more). Similar high transparency values could be measured in water tanks, with water pumped up from 30 to 40 m depth, that means from the hypolimnion. In these containers the transparency surpassed usually 400 or oven 500 cm.

5.8 BIOLOGICAL ASPECTS

A. Life on the dry shore (supra-littoral) and the littoral zone of the reservoir

The direct environment of the Lake Nasser-Nubia was after progressive flooding of the fertile landscape of the Nile Valley pure desert, without a single green plant. Vegetation was found only further from the lake in special localities, e.g. where granitic dykes crossed wadis, storing occasional rain water deep below the surface for 20 or even more years. In such extraordinary habitats only few extremely drought resistant, slow growing plants, e.g. some *Acacia* trees were able to survive for decades.

Photo 5.8 Dragonflies at noon around a shallow rock-pool on the lake-shore at Wadi Halfa. All insects keep themselves in a vertical position possibly to reduce evaporation. (August 1973) (Entz 1979)

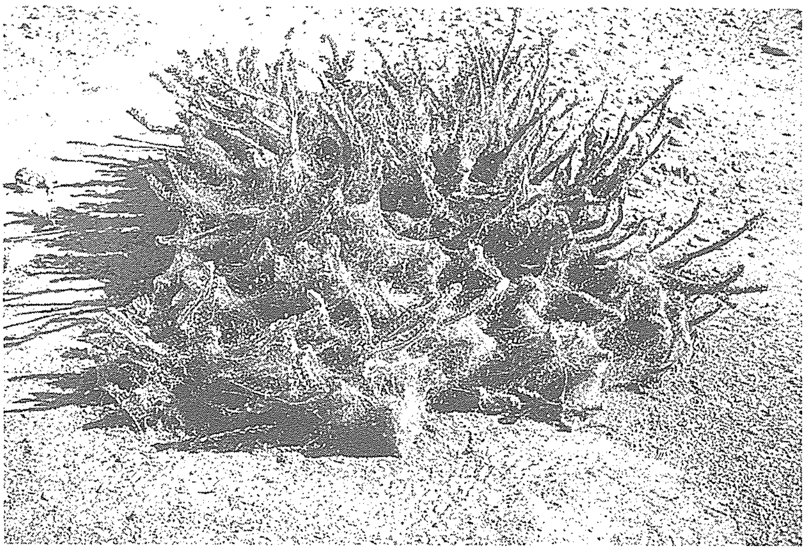

Photo 5.9 *Hyoscyamus muticus* on the lake-shore covered by spider-webs heavily loaded with dead chironomid midges. (February 1973) (Entz 1979)

These few plants possibly gave fodder for some very scarce mammals, like gazelles, Nubian goats etc., whose footprints sometimes could be detected in the neighbourhood of the lake.

In late autumn, when the peak of the regular flood period was over, on the still humid sandy beaches at once seedlings of a common weed, *Glinus lotoides* (Aizoaceae) appeared in immense numbers. Their seeds have been brought most probably by the flood water. These little plants were arranged in a stupefying way perhaps moving the seeds by smooth wave action along the edge by shrinking water level in parallel rows. These rows were in 1970 at equal distances from each other, as they would have been sown by a machine.

During the following years (1971 to 1973) taller, sometimes bushy plants (*Hyoscyamus muticus, Rumex* spp., *Tamarix nilotica, Citrullus colocynthis* etc.) became acclimatized further from the shore ordered according to species behind (i.e. above) the *Glinus lotoides* belt.

The newly appearing vegetation formed as on a magic touch a beautiful, rich colourful "park" amidst the desert in localities, where green plants were certainly absent for many thousands of years (Photo 5.7).

All these gave an indication that in this area the desertic soil is not necessarily infertile. On the contrary it seems suitable for agriculture, needing only water supply.

This is the more probable, because the water of the Nile and also that of the lake contains inorganic and organic nutrients in abundance.

Later, particularly from 1974, spreading from the north (i.e. from the High Dam area), several grasses (*Eragrostis aegyptica, Phragmites communis* etc.) and *Tamarix nilotica* became the dominant species on the shore of the lake. The trend of these changes achieved that the appearance of the vegetation in the littoral and supra-littoral zone became gradually similar to that of the earlier Nile River. So the ancient Roman saying became justified: *Naturam expellas furca, Tamen usque recurret,* (you may expel nature by force, but it always returns).

Basic, sometimes unexpected, changes have also been observed regarding the terrestrial and amphibious fauna. These changes were influenced by two main factors:

1. The complete disappearance of previously available vegetal and animal food in their terrestrial habitats.

2. The epidemic propagation of chironomids (lake flies).

With regard to No. 1, we found still some few remnants of rats and jumping mice (*Jaculus jaculus*) around the lake shore in 1970, but none of them in following years. Some few exceptions were, outside the previously mentioned gazelles and Nubian goats, snakes and scorpions. So very characteristic "body prints" of jumping snakes (probably the horned viper, *Cerastes cerastes*) could be found several times all along the shore on quicksand bars, during the filling stage of the lake.

Scorpions were always present in the area. On some localities they became so common, like in Khor Allaqi, that specimens could be found numbering in the hundreds hiding under flat stones. But at night these dangerous animals crept out from their hiding places and walked around particularly on hot windy nights, with tails riding high searching for food.

As for No. 2. An epidemic propagation of midges (chironomids) is well know all over the world from newly formed freshwater bodies (Redeke 1948, Morduchai-Boltovskoi 1978). As known, the larvae of these insects are able to utilize organic debris in the bottom layers of the shallow littoral of different water bodies very successfully. Their extremely fast propagation was very obvious in Lake Nasser-Nubia during its filling stage.

So in lake sections, soon after the fertile grounds of the Nile Valley have been flooded, and the water-body reached lacustrine characteristics, i.e. currents were almost completely absent, bottom dwelling larvae of chironomids propagated themselves immediately in almost innumerable amounts.

Following the long-lasting inundation and the rising water level of the High Dam Lake from 1964 to 1975, it became obvious, that peaks of swarming chironomids were shifted year by year from north to south along the main axis of the lake, reaching finally Lake Nubia in 1972. But the number of swarming midges per m^2, counting the floating exuviae on calm water surface, decreased continuously towards the 2nd Cataract. It is suggested that the presence of currents in the southern sections make these habitats less suitable for the development of the dominating species in the lake. Accordingly in the Gorge region of Lake Nubia where remarkable water currents are always present, the numbers of chironomids was almost negligible. Instead, swarms of ephemerids could be observed there. But these insects were by no means as numerous as the chironomids elsewhere.

Concerning the seasonal distribution of swarming midges, in the years 1970 to 1974, the following could be established.

Peak values of swarming midges could always be registered just before the front of the turbid flood water reached the spot, but by already increased level of the old water. The first big swarms of chironomids could be observed in Lake Nubia, around Wadi Halfa in the years 1970 to 1974 in August, by 28 to 30°C water temperature. The latest swarms occurred in December near the High Dam when the temperature of the water was only 22 to 24°C. Accordingly it became evident that water temperature has practically no effect on pupation or emergence of the present dominant species.

On the other hand, some role could be played concerning the mass-emergence of chironomids by the decreasing conductivity of the water in their habitat from 270 to 300 μMhos within the old water to 190-240 μMhos in the flood water (Fig. 5.10).

But as suggested the main factor influencing or even regulating the date of mass emergence of adults in the connective lake sections is the remarkably increasing hydrostatic pressure. This is very obvious, considering that the per cent values of the increment of the hydrostatic pressure is the strongest in the shallow littoral, e.g. in 3 to 5 m deep water areas, the most preferred habitats for chironomid larvae. Here the growth of hydrostatic pressure may surpass 100% of the original or even more.

Accordingly the peak of chironomid swarms appeared strictly correlated to the progressing yearly flood.

Masses of chironomid pupae ascended during the afternoon from the lake bottom to the surface. There the insects left their pupal skins in great numbers, occasionally 100 to 200 specimen/m^2. The floating exuviae appeared like a lifeless pleuston on the spot. The young adults flew up forming huge swarms particularly around sunset on windless days. After their bright flight and the deposition of their eggs on the water surface, most of them descended on the shore. They gathered there in super-dense grounds preferring wind protected places, behind rocks, in dense vegetation or in holes. Most of them died overnight in billions on their gathering places forming there a cover of foul-smelling thanatocoenoses some millimeters or several centimeters thick.

Giant outbursting populations of chironomids usually did not appear within the same lake sections longer than in two following years. Thereafter their numbers decreased rapidly to a much lower but enduring level.

This phenomena might be due to the following two main factors.

1. The year by year ascending water level with strongly increased hydrostatic pressure.

This made the development of larvae of the dominant species intolerable, though in the upper bottom layers abundant food was still available for them as in the benthic area of the flooded green belt of the Nile Valley.

2. The epidemic like propagation of many groups of arthropods and vertebrates, as spiders, dragonflies, and toads decimated the number of adult chironomids on the shore or consumed their larvae in the water as larvae of dragonflies (Photo 5.8).

The standing stock of chironomids was suggested to be 100,000 tons in the lake during the years of their main development, from 1969 to 1973. Accordingly they played during that period as larvae, pupae and on the surface film drying members of newborn adult an important role as multitudinous and easily available food for several fish species.

It is worth mentioning that masses of the exuviae were brought together with cadavers of these insects and other organic debris by gentle breezes to the shore. All these materials formed just beside the shoreline a small, narrow, but actually many kilometers, sometimes even 100 kms, long drifts. In those drifts very vivid bacterial activity took place. Furthermore, tremendous numbers of flies were crawling around them, feeding on the decaying materials and in the mean time, flying adult midges served as basic food for toads. These amphibians, as observed several times, after hiding during the day, came out in the evening hours to the border of the lake by hundreds on each kilometer of shoreline.

Accompanied by flies and toads, millions of spiders were stocking the shore on places where terrestrial plants occurred. These plants were covered very frequently by dense glittering spider's webs, full with dying or dead chironomids (Photo 5.9).

On the other hand as soon as the number of chironomids, playing during their mass development a most important role in the food chain of the littoral zone, was strongly reduced the number of individuals belonging to groups feeding on them became also scarce or these animals disappeared completely from the area.

Similar to the fate of the chironomids was that of certain small-sized waterbugs, belonging to the family of Corixidae. These insects, feeding mainly on zooplankton and living near the water surface in shallow water showed, in the 70s, a real outburst in numbers. Their very characteristic subaqueous chirping sound could be heard almost all over the littoral area in 1970 to 1972.

But these bugs became excellent food for young tigerfish, similarly becoming widespread in the lake in the same period. The stomachs of these fish was often totally filled with these bugs. Sot is suggested that the ravage caused by the tigerfish was the main cause of their reduced numbers or even disappearance.

Lastly, it should be mentioned that during the period outlined the number of crocodiles increased about tenfold to several hundreds around the lake. This might be due mainly to the fact that in almost complete absence of human population they could live and propagate undisturbed.

For migrating birds all these changes had no effect at all. For example, swarms composed by thousands of European storks (*Ciconia cidonia*) followed the same route as before, along the area. They used the shore of the lake as resting places just as those of the Nile River in the earlier times.

A rough estimation of changes of the most characteristic faunal elements near the High Dam in the Khor el Birba (= Khor el Ramla) during the filling stage of Lake Nasser are summarised in Table 5.4.

Table 5.4 Rough summary of spending, propagation and reduction of terrestrial and amphibious faunal elements around Khor el Birba during the filling stage of Lake Nasser (1968-1974).

Animal groups / Years	1968	1969	1970	1971	1972	1973	1974
Chironomidae (midges)	I	I	P	P	D	F	F
Corixidae (water bugs)	-	I	P	P	D	D	N
Odonata (dragon flies)	-	N	N	F	F	P	D
Diptera (flies)	-	I	P	P	F	N	N
Arachnoidea (spiders)	-	N	I	P	P	D	D
Scorpions	-	F	F	F	I	D	F
Locusts and caterpillars	-	N	N	N	N	F	I
Toads	-	F	P	P	D	N	N
Snakes	-	+	+	+	+	+	+
Crocodiles	-	+	+	I	I	I	I
Geese	F	F	F	I	I	I	I
Rats and *Jaculus jaculus*	+	+	+	N	N	N	N
Gazelles, nubian goats, etc.	-	+	+	+	+	+	+

Explanation: N = Not found, F = Only few present, P = Peak development, + = 1-2 single specimens, I = Increasing population, D = Decreasing numbers.

B. Life in the main water body (pelagial, sub-littoral and benthal).

The High Dam Reservoir; this permanent waterbody showed during its existence all the same appearance. But due to important physical and chemical changes within the waterbody life in the open water areas of the lake i.e. its sub-littoral, pelagial and benthal, underwent similar basic changes as terrestrial and amphibious life near the shore.

With increasing water level the transflowing time of the Nile water masses increased from a few days to about a year. So instead of a riverine environment, lacustrine conditions became dominant. This situation became suitable for more abundant development of algae. First masses of pelagic and above all epilithic diatoms, forming rich periphyton + epilithon, occurred. Diatoms, particularly their periphytic and epilithic species turned to excellent food for the most numerous and, as an Egyptian national dish, the most important group of fishes, the *Tilapias*. This happened already during the filling stage, but was unchanged during the stabilisation period.

Green algae e.g. colonies of *Volvox* spp. were spreading from the High Dam to Lake Nubia. These algae were the most numerous in the Kalabsha area (100 km from the High Dam) in 1970 and near Wadi Halfa (about 300 km from the High Dam) in 1972. In this way these green algae were "accompanying" the peak of swarming chironomids.

In the confluence of the gorge region, around the 2nd Cataract, bluegreen algae appeared in enormous masses; *Microcystis aeruginosa* being the dominant species. *Microcystis* formed very heavy waterblooms, forming on some places several centimetre thick floating layers on the surface, like a bluegreen coloured sourcream. This layer was often driven to the shore forming a bluegreen drift with a very peculiar smell.

The water-bottom of the shallowest extensions of khors were often covered by fields of *Chara* spp., surrounded by extremely clean water.

During the first years of its formation, aquatic macrophytes were absent from the lake. From 1971-72 *Potamogeton pectinatus* occurred in great numbers in shallow waters down to 4-5 m depth. From 1973 *Najas* species occupied many habitats below the *Potamogeton* fields down to 6 or even 9 m. These macrophytes started to grow near the High Dam and were spreading quickly towards the south. Areas covered by dense carpets of these plants became good shelters for invertebrates and young fishes.

For example, a freshwater shrimp, *Caridina nilotica* breeding there in masses, offered already in 1974 big quantities of this favoured prey for young specimens of Nile perch (*Lates niloticus*), a very delicious and most valuable carnivorous fish of Africa, playing also an important role in the fisheries of Lake Nasser.

The most dramatic changes occurred in the fauna of the benthic region. As well known, the ancient river bed was a preferred habitat for innumerous mussels, whole bulk was composed by big specimens of *Corbicula nilotica* (Rzóska, 1978).

The formation of the new huge reservoir caused spectacular changes. During the first extended summer stagnation period from May to September, or even till December in 1970, the deepest water layers and the surface of the sediment became for long periods unoxic, particularly in areas of the old river bed.

As experienced from our bottom samplings in Lake Nasser, a mass mortality of the oxybiontic *Corbiculas* took place in the first years of the filling reservoir, resulting in widespread dense thanatocoenoses particularly within the old Nile River bed from the Aswan High Dam to Wadi Halfa. Further to the south, around the 2nd Cataract, bottom samples contained no shells of mussels. This happened probably because of the immense silt-sediments covering the shells with a thick layer of mud (see Fig. 5.11).

But further to the south in the semi-riverine or further pure riverine sections of the Gorge-region of Lake Nubia, due to the permanent presence of remarkable currents and an abundance of oxygen, undisturbed mussel-beds could be detected alive.

Though it is worth mentioning that from 1973 young mussels invaded the littoral zones on both sides of the lake as new colonizers. This could be observed in localities rich in oxygen, and moderate silt deposition during the flood periods.

Mussels and other bottom dwellers of the benthos formed in the old Nile the main food-base for several bottom-feeders (e.g. certain fishes, as members of the Mormyridae family).

No wonder that due to the changed conditions riverine fish species gradually disappeared from the reservoir.

However, during the regular flood season many riverine elements are spread within Lake Nubia and in smaller or greater extent in Lake Nasser too. The extension of this turbid watermass depended on the lake level and the strength of the flood, accordingly the proportion of the flood water-mass and the actual lake volume. These circumstances regulate the spreading and distribution of fish species with typical riverine of lacustrine features.

Due to these conditions, in the temporarily or permanently unoxic benthic zones only organisms could be prosperous, being able to resist the anoxic milieu. These organisms made in the mean time excellent use of the rich organic matter content of the mud layers in question. Under these conditions a remarkable though restricted propagation of red chironomid larvae, belonging to the plumosus group were there observed, but above all an immense reproduction of Tubificidae (Oligochaeta) took place. Based on the available mud samples taken in different seasons during the years 1970 to 1974, the total biomass of these reddish worms was suggested to reach in the entire lake at least 100,000 tons.

A progressive eutrophication process was demonstrated within the lake by the rate of primary production. Its estimated value was in 1959 behind the Old Aswan Dam 1.06 $gC/m^2/day$. The same values were in Lake Nasser in 1970 approximately 3 $gC/m^2/day$ and in 1979 about 7.5 to 12 $gC/m^2/day$ (A.F.A. Latif 1981).

During the same years zooplankton became also richer. Mean values of copepods were in August 1976 before the arrival of the flood 24.9 ind/l, that of cladocerans 6.9 ind/l, while that of rotatorians did not reach more than 0.15 ind/l (A.F.A. Latif 1977). Accordingly, the most abundant members of zooplankton were copepods (76 to 80%), followed by cladocerans (20%) and by almost unimportant values of rotatorians (1 to 2%), (A.F.A. Latif 1981).

In the flood water the mean numbers of zooplankton organisms were strongly reduced. But in khors being almost unaffected by the flood water, zooplankton densities remained unchanged all year round. From these "shelters" zooplankton might be able to spread into the main channel when the flood was over.

5.9 FISH FAUNA AND FISHERY

Since 1964, 57 species of 15 fish-families have been recorded from the High Dam Lake (Latif 1976)[(2)]. Before the High Dam was built, the bulk (about 70%) of fishes in River Nile was, according to fishery statistics, composed by riverine forms, as omnivorous species (e.g. *Labeo* spp., *Barbus* spp., *Synodontis* spp., Schilbeidae and Mormyridae), carnivorous fishes (e.g. *Hydrocynus forskali*, *Bagrus* spp. *Lates niloticus*), and plankton feeders (e.g. *Alestes* spp.). Real lacustrine forms as Cichlidae (e.g. *Tilapia nilotica*)[(3)] was also present but in almost unimportant numbers.

A reverse situation developed in Lake Nasser. The riverine forms were pushed during the filling stage into the background, while the lacustrine ones showed an immense propagation. Particularly *Tilapia nilotica* together with the newcomer *Tilapia galilaea* (present in the lake since 1970) became the dominant species. *Tilapias* gave about 27% of the total fish landings in 1968 and more than 90% in 1981.

To increase the fish yield in Lake Nasser more fishing effort and suitable organization for transport of iced fish by boat on the lake to the Aswan harbour and further by rail to Cairo were wanted. Accordingly the number of fishermen had to be increased from 151 (1962) to 9,000 (1982), and that of boats from 200 to 1,962 (in 1966 and 1978 respectively), together with successful cooperative societies.

Most of the fishermen were recruited from the north - Sohag and Qena districts. This was not an easy task, because living conditions in the lake area were hard, and the fishermen had to leave behind their families, only visiting them twice or three times a year. And beside there is an old Egyptian saying, "better 10 miles north, than 1 mile south". So several incentives had to be given to them to accept this job.

Several problems were also experienced with ice supply, the route of fish transport to Aswan, the time table for fish collection etc.. But as mentioned above, success was eventually achieved. Still further steps have to be done to provide the fishermen on the spot with normal accommodation to live finally together with their families. That means that new settlements around the lake are still badly needed.

The composition of the fish-fauna showed remarkable, mostly gradual changed in time from 1965 to 1975, and in space from High Dam (Lake Nasser) to the Gorge-region in Lake Nubia. In time the gradual scarcity or almost total disappearance of omnivorous fish species and bottom feeders (e.g. the Mormyridae), was recorded particularly in the Egyptian part of the High Dam Lake.

On the other hand it was very obvious how periphyton feeders, the most important for human consumption were spreading. In the mean time total fish landings were within the planned area of the High Dam Lake in 1966 about 750 tons. The yield grew up in Lake Nasser to 12,000 tons in 1974 and reached in 1981 more than 33,000 tons (Fig. 5.12).

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(2) The content of this chapter on fishes and fisheries is almost entirely based on results of detailed studies accomplished by Dr. A.F.A. Latif and his team, published among others in 1973, 1974, 1976 and 1983.

(3) At present the accepted taxonomic names of *Tilapias* present in Lake Nasser are *Sarotherodon nilotica* and *Sarotherodon galilaea*. Still *Tilapia* is commonly used all over the world.

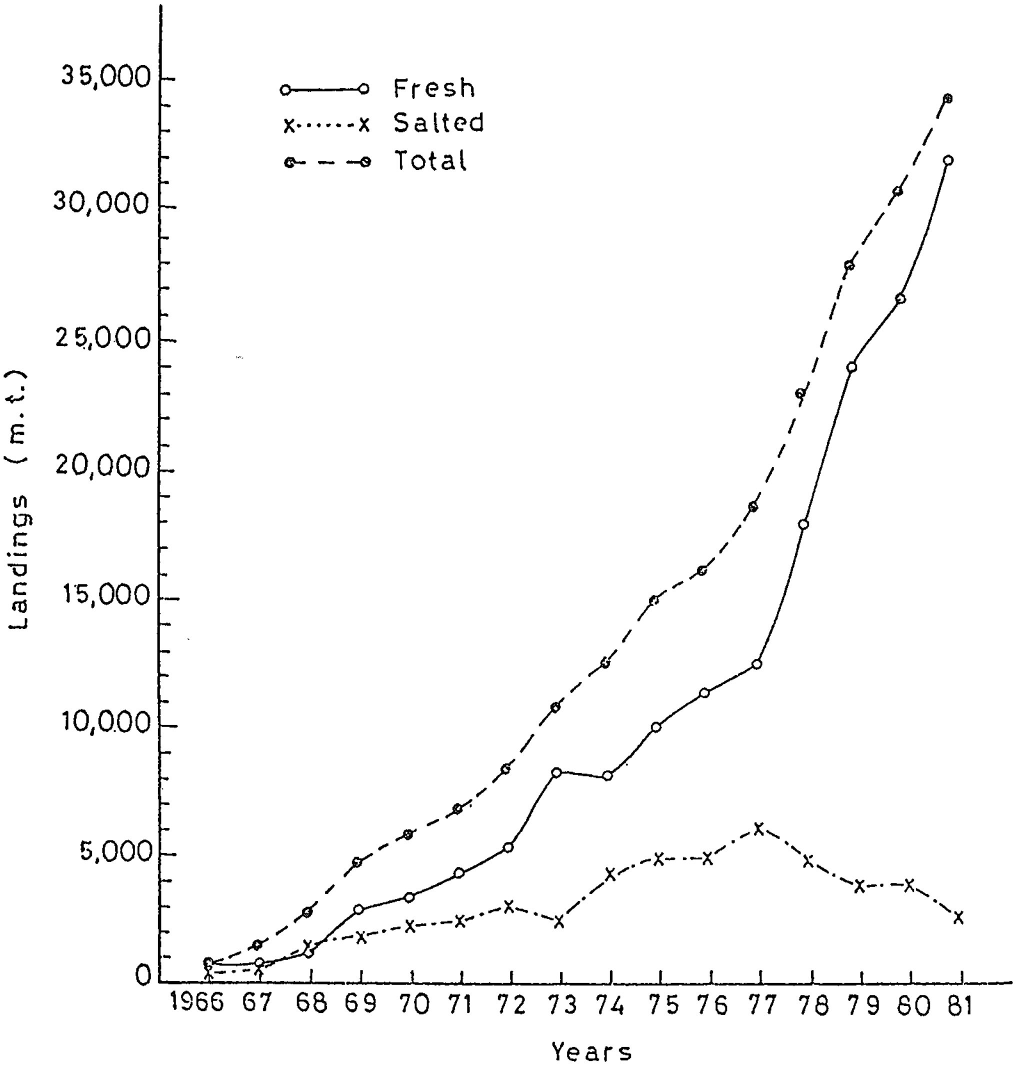

Fig. 5.12 Lake Nasser yields

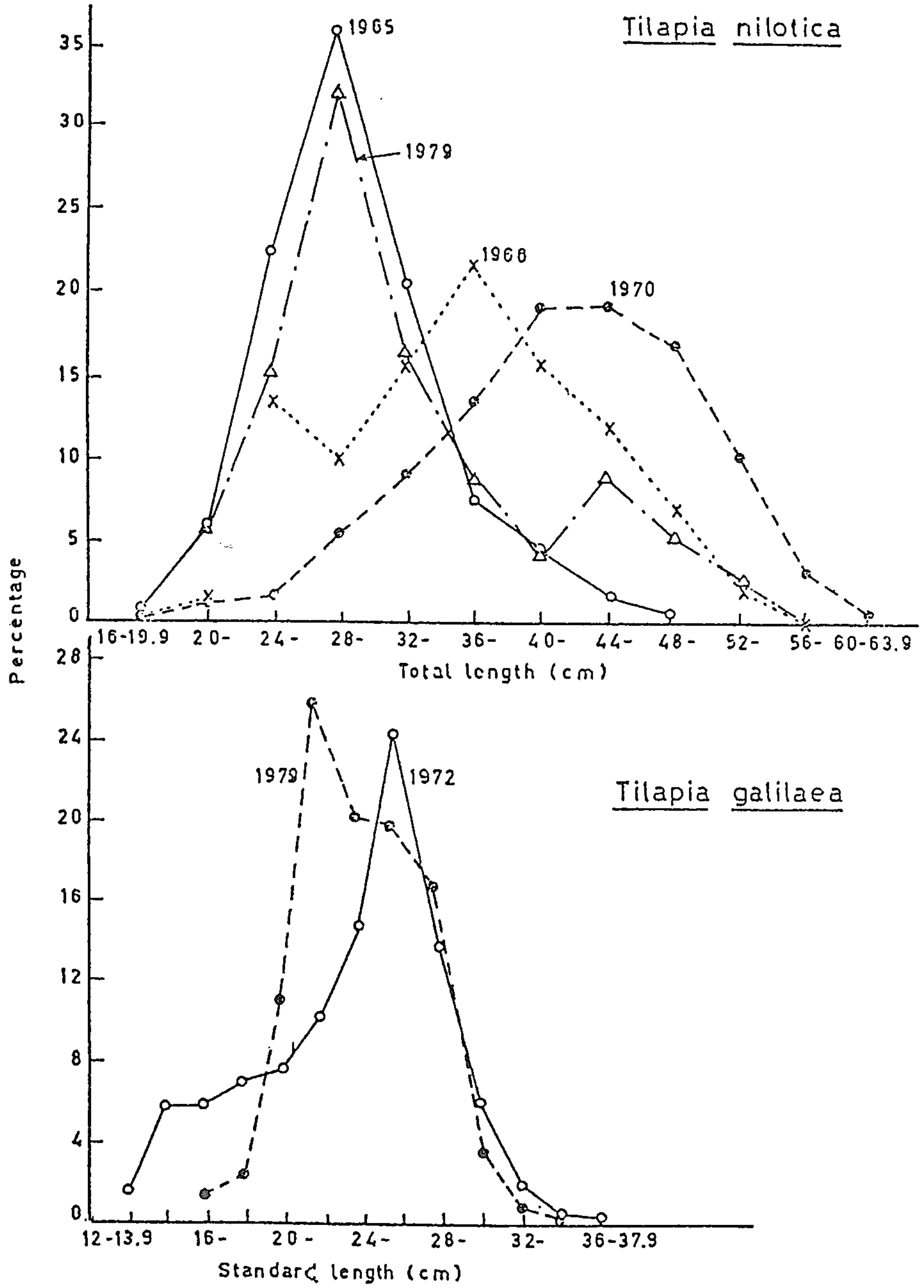

Fig. 5.13 *Tilapia* size and percentage in Lake Nasser

The economic value of the fish from Lake Nasser was increasing strongly, due to the following three main reasons:

1. Fishery in the Egyptian section of the Mediterranean Sea almost collapsed after the closure of the High Dam. So landings were reduced from 38,000 tons in 1962 to about 20,000 tons in 1979. An explanation of this event might be given by the indirect effect of strongly reduced amounts of nutrients flowing into the sea, among others due to the following:

   a. The complete sedimentation of the Nile-mud in Lake Nubia;
   b. The consumption of most of the dissolved nutrients within the High-Dam lake by algae and macrophytes;
   c. The reduced amount of Nile-water reaching the sea coming into being by very intensive irrigation in areas below the High Dam. Accordingly the fish-stock around the Nile-Delta in the sea is strongly reduced.

2. The main source of animal protein in Egypt, like that in most African countries, is fish. The decreasing amount of sea fish on the market could be compensated in this way by increasing amounts of fresh, frozen and salted fish from the lake.

3. The need for fish for food increased in Egypt in the mean time in a very high degree due to the enormous growth of the population in the country in the last decades.

4. Periphyton feeders expanded enormously, particularly *Tilapia* species, mostly in the Egyptian part of the lake. An interesting trend could be observed in the distribution of omnivorous fishes too. Many of them were present in Lake Nubia, particularly in its Gorge-region, all year round.

Evaluating these phenomena two special situations should be mentioned.

1. *Tilapia* spp. became in Lake Nasser from the mid-70s, the dominant fish-group in the summer stagnation period giving in 1982 more than 95% of the fish landings. It is worth mentioning that during this time (the stratification period) the fishes were concentrated in the upper water layers so fishery was easier and the most successful in the summer season, giving the greater part of the yearly catch. But during the flood season and the winter circulation period the proportion of *Tilapias* was reduced, and the *Alestes* spp., together with the tiger fish (*Hydropcynus forskali*), accounted for about one fourth of the total catch, sent to the market as salted fish.

2. The composition of the fish-stock in Lake Nubia was very peculiar. There the Nubians, the earlier local inhabitants almost did not fish. Only the fairly common water-turtles were hunted for food.

As a consequence of self regulation of the fish-fauna, there occurred numerous very large carnivorous fishes and relatively few smaller sized specimens of other species. This situation was experienced by us, at the confluence of the Gorge-region, where during one single night in February 1973, with two experimental sunken gill-nets beside some few kilograms of small sized fishes, four specimens of Nile-perch (*Lates niloticus*) weighing more than 40 kg each and one "king size" 19 year old female (199 cm long, weighing 175 kg and containing more than 1 million eggs) were caught.

It is remarkable that *Lates niloticus* (Family Centropomidae) is surprisingly similar in its exterior and its habits to *Stizostedion lucioperca* (pike-perch, fam. Percidae) widespread in the northern temperate zone. Its flesh is very tasty, a real delicacy. *Lates* gives not a great, but a very valuable deal, in catches all over the lake.

5.10 AGRICULTURE

The shores along the sections of the Nile studied, where now Lake Nasser is undulating were covered formerly by rich riverside vegetation and cultivated lands growing on almost 1000 km^2 area. All these are now sunken in water together with wheat fields, kitchen gardens and about 500,000 very valuable date-palms (see Photo 5.10).

In the late 60s the question was raised as to how far the pure desertic soils accompanying nowadays the shores of Lake Nasser are:

1. Suitable for agricultural use, and if so;
2. remunerative for cultivation.

With regard to the first question, for suitability the answer is definitely positive. The soil on flat or slightly inclining shores is light sandy loam with low moisture holding capacity, e.g. in the Tushka area (a huge almost flat area near Abu Simbel) the composition of the soil expressed in per cent is as follows:

Composition of the soil in per cent

Components / Layer	Gravel	Sand: coarse	Sand: medium	Sand: fine	Silt	Clay
0-5 cm	0.2	13.7	18.4	33.3	9.0	25.6
5-60 cm	-	13.0	20.0	44.0	8.5	12.5

The lime content seems suitable for cultivation. Experiments in that area were, beside the widespread upcoming wild vegetation, supporting this view.

In the Abu Simbel Experimental Farm in 1973 in 10 to 150 cm deep sandy soil with irrigation the following promising results were achieved in comparison with those known from the Aswan area in the classical fertile Nile valley.

Crops in kg/feddan (1 feddan = 0.4 Ha)

	Wheat *Triticum sativum*	Barley *Hordeum vulgare*	Gram or chickpeas *Cicer arietinum*	Fenugre *Trigonel* sp.
Abu Simbel	1200	1440	1500	780
Aswan	575	1080	600	475

Beside some mediocre results from orange trees, melons were very successful. It could be concluded that before cultivation starts, plantation of wind breaking trees is inevitable to protect crops and fruit trees in these more elevated areas against attacks by sand. By experiments at Abu Simbel only irrigation was exercised. No nutrients have been added or if so, only in very slight amounts.

These good results are among others probably due to the high nutrient content of the lake water used for irrigation purposes.

With regard to the second question, the answer in Lake Nasser area is not unanimous, whether:

a. drawdown cultivation should be adapted (i.e. use of the land strip between high water level and low water level); or

b. territories above the high water level are considered where cultivation is only possible by irrigation.

In the first case (a), the answer is again affirmative. This is the more important, because by the foreseen working level of Lake Nasser the surface of this land strip is about 480 km^2, where enormous water quantities are evaporated utilized by cultivated plants or without any use (Fig. 5.14). Accordingly it is advised to use this zone between high and low water level for kitchen gardens, water melon and date-palm plantations. Particularly the latter are very suitable for the lakeshore in question. Beside the time of decreasing water level new settlers (e.g. farmers, families of fishermen) could make use of the time of upcoming floods by sowing in the water a special rice variety, the so called "floating rice", nowadays widespread in India.

It must be reminded that by planting date-palms only shoots brought from other parts of the Nile Valley should be used to avoid introducing any date-palm disease from foreign countries, causing perhaps unthinkable catastrophes for the Egyptian and Sudanese stocks.

In the second case (b) because of the scarce population in the area, the difficulties and high expenses for transport, large scale irrigation in the area in question requires much consideration.

The situation is quite different in the Lake Nubia area. There at present, and doubtless in the coming decades too, on flat shores immense amounts of Nile-mud are and will be deposited (Photo 5.3). Any kind of agriculture that has been used in the old Nile Valley before is suitable there. This is already successfully going on in the Wadi Halfa area in Sudan.

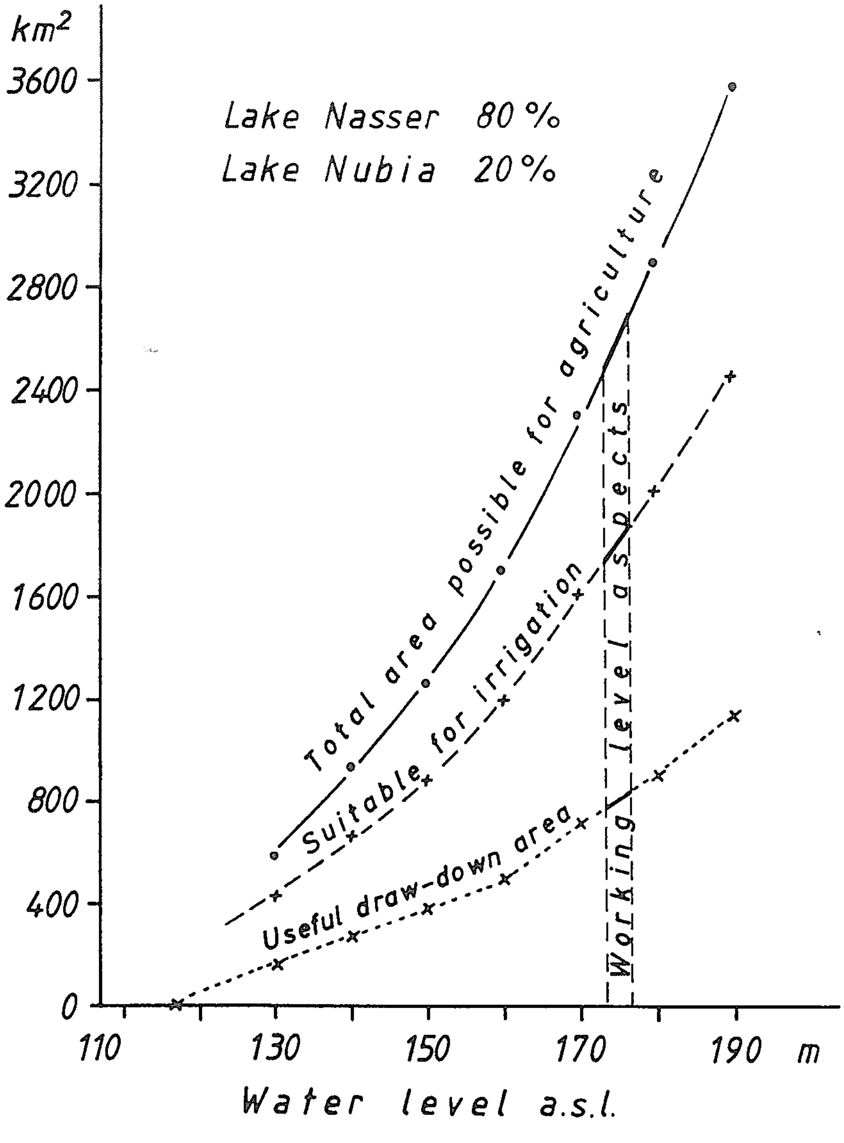

Fig. 5.14 Aspects for agricultural use of the HD-Lake area.

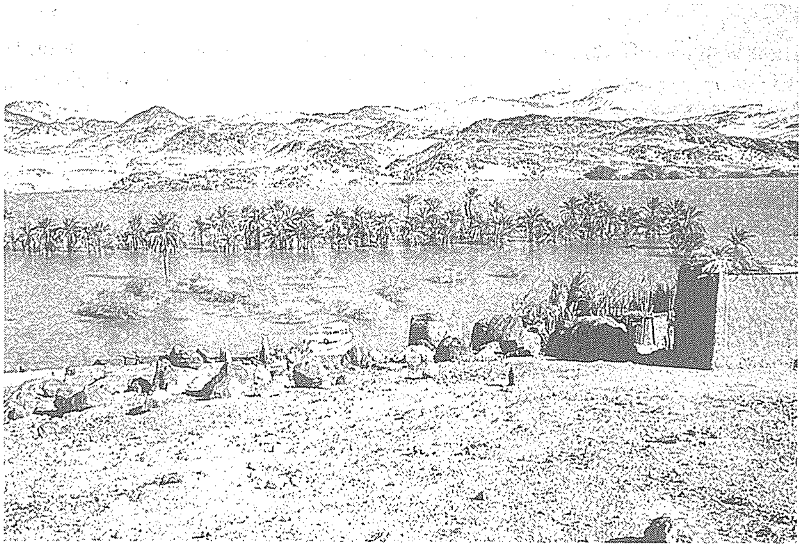

Photo 5.10 Some of the half million date-palms of Nubia, flooded by the lake in December 1972. (Entz 1969)

5.11 ANIMAL HUSBANDRY

Revival of animal husbandry in the area of Lake Nasser is only possible if the necessary fodder will be produced locally. Anyhow, goats, sheep, camels and particularly donkeys, originating from Nubia where even nowadays some wild specimens are living, are the possible species for animal keeping. Some results in this aspect could be already observed in the Gorge-region of Lake Nubia in 1973 and 1974.

5.12 HUMAN SETTLEMENTS AND RESETTLEMENT PROBLEMS

About 40,000 people had to be evacuated from the Nile Valley between the High Dam (north) and the Dal Cataract (south), because of the remarkable rising water level - by more than 50 meters in Egypt (Lake Nasser), and around New Halfa in the Sudan (after inundating the whole town of Wadi Halfa), and 40 to 10 m in the Gorge-region of Lake Nubia above the 2nd Cataract. Simultaneously all fertile arable lands were flooded, including about 500,000 date-palms, the most valuable possession of the old inhabitants.

The Egyptians have been resettled north of Aswan along the Nile, where they got as compensation for their lost fortune newly built houses in well designed new villages with much better living conditions. Similar possibilities were offered to the evacuated Sudanese families. Still many people tried to stay on the spot till the last minute, not believing the great artificial flood. Nevertheless, later they had to occupy the offered new homes. Many of the previous inhabitants, particularly the young people, were content with the new situation, but some others, particularly the elders, were unhappy.

Due to that, some of the latter left the new settlements, returned to the vicinity of their birth-places, and tried to start a new life digging on their own irrigation channels from the lake shore under extremely hard circumstances.

On the other hand, around Lake Nubia, particularly near the town New Halfa, located above the completely inundated Wadi Halfa, farming activities already started in 1972-73, and became very promising. Similarly the beginnings of animal husbandry could be observed around Lake Nubia.

5.13 HEALTH CONDITIONS

There was a fear after the formation of Lake Nasser that malaria, carried by mosquitoes will spread again all over Egypt, killing millions as happened about a hundred years ago. It was supposed, that the lake will form a connecting link between Egypt and the main spreading area of the most dangerous vector organism, the mosquito (*Anopheles gambiae*), in Sudan. Fortunately, the aquatic larvae of this perilous insect could not be detected neither in the littoral of the lake, nor in the few seepage places.

On the contrary they were present south of Lake Nubia where, with international cooperation, they were stopped by regular spraying of their breeding places.

Another danger was indicated by the possible spreading of schistosomiasis. This was the more realistic because its vector organism some aquatic snails (e.g. *Bullinus truncatulus* and *Biomphalaria alexandrina*) were found in several littoral localities in shallow water in great numbers. The danger was the more acute because several fishermen coming from work to the lake were already infected by this disease in their home towns (Sohag and Qena). Fortunately there is only a single gate to reach Lake Nasser: Aswan. Therefore, all people coming for work on the lake or returning to their home towns were checked at a sanitary station in Aswan and stopped and cured, if necessary, before allowed passage.

Yellow fever is a well known disease in the Sudan. For this reason all travellers arriving at the Sudanese border from Egypt have to show their documents proving inoculation against yellow fever.

5.14 GENERAL CONCLUSIONS

Last but not least a question that is always posed whenever the subject of Lake Nasser is broached, must be asked here as well: "Is the construction of Lake Nasser-Nubia good or bad for Egypt?"

Based on my own, more than 5 years long experiences (1969-1974) and of the opinion of several competent specialists (1983), but not of journalists influenced by politics, the following might be concluded.

The formation of the man-made lake in question had many quite different effects. Some of them are positive, others are negative.

Some of the negatives are as follows:

1. Recession of fisheries around the Nile-Delta in the Mediterranean.

2. Huge amounts of water are evaporated from the lake without meteorological consequences (e.g. precipitation).

3. Total supply deficiency of fertile Nile-mud below the High Dam.

4. Loss of remarkable amounts of soil by riverine erosion below Aswan reduced water-supply by the Nile.

5. Intrusion of sea-water into the Nile-Delta because of strongly reduced water-supply by the Nile.

6. Higher natron content of the water used for irrigation and formation of natron-salt-crusts on some irrigated arable lands.

The positive effects are:

1. Danger of flood catastrophes is eliminated for several hundred years.

2. Irrigation below Aswan is ascertained all year round, making a summer and winter crop possible.

3. The area for irrigated land could be increased (e.g. Edfu area).

4. The enormous electric energy produced since the construction of the High Dam plays an important role in energy supply of whole Egypt.

5. The achieved energy makes the production of N-fertilizers possible in optional amounts, to replace the usual mud-cover of the Nile.

6. Fish yield from Lake Nasser with more than 30,000 tons per year replace by far the loss of the Mediterranean fish.

Considering the total effect of the High Dam as 100 per cent, it is suggested that the positive effects give 60%, and the negative ones 40%. All in all the balance seems to be positive (+20%).

Considering even in very dry years in NE Africa, irrigation and accordingly life in Egypt is relatively undisturbed, i.e. there is no famine, it can be concluded that the construction of the High Dam should be evaluated as very positive.

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CHAPTER 6

WATER QUANTITY AND QUALITY IN LAKES AND RESERVOIRS FOR HUMAN USES

Ernst A. Nusch

6.1 INTRODUCTION

Water quantity and water quality are inter-related. So water quality can be managed not only by wastewater purification but also to a certain extent by regulation of water quantity, e.g. by low flow augmentation with water discharged from upstream reservoirs.

As there is a relation between typology and limnology of stagnant waters it is necessary to differentiate between lakes and reservoirs and perhaps other types of stagnant water bodies (e.g. river impoundments), water quality is not merely a function of input, dilution and basic metabolic processes.

As far as water for human uses is concerned the production of potable water and some other patterns of multiple use of reservoirs, e.g. recreational activities, are generally most important in Germany and other countries with temperate climates. In other climatic and geographic situations water for agricultural irrigation, livestock watering, aquaculture and probably other human activities may be of prime importance.

Therefore it is not possible to give general instructions how to adjust water quality to the intended use. Practical advice for remedial actions should not be given without recognition of the local situation, the special set of priority problems and the possibilities and constraints of the different countries. This is particularly true for the relation of water quantity and water quality and the resulting problems. Poor water quality may even be better than no water at all.

Bearing this in mind at first the subject is dealt with from a general, more theoretical, point of view and then some examples of practical solutions derived from the experience with water quality management in the drainage basin of the Ruhr River are conveyed.

6.2 TYPOLOGY OF STAGNANT WATERS AND IMPLICATIONS FOR WATER QUALITY

6.2.1 Size and volume

Apart from the interest of delighted children for rain puddles and mudholes, human usage is mainly concerned with water bodies above a certain size or volume. Small ponds in a rural area serve primarily for the purpose of fire fighting (and sometimes for bathing and fishing). Larger natural lakes, especially in populated areas and man-made reservoirs mostly show multiple use patterns.

Before trying to establish a relationship between water quality and water utilization it is advisable to point out some differing features of natural lakes and man-made reservoirs.

6.2.2 Situation of outflow

Most important is the fact that the outflow in a natural lake is normally situated at the surface whereas in a man-made reservoir the water is mostly withdrawn from the bottom outlet or from deep water layers.

Water discharge from surface (trophogenic) layers implies that a great deal of organic material, e.g. planktonic algae, will leave the lake almost undegraded. This is a considerable exoneration of the oxygen budget, particularly when the water body is stratified during summer stagnation and microbial degradation takes place in deeper water layers. Reservoirs, in contrast, are generally operated with hypolimnetic water discharge. So the ratio between trophogenic and tropholytic volume becomes more and more unfavourable in the course of the year and consequently hypolimnetic oxygen depletion may even occur in mesotrophic reservoirs [1].

For drinking water supply the raw water is generally taken from the upper hypolimnion, where the water quality is considered to be best as far as algal content, oxygen level and degradation-products are concerned. Bottom discharge is advantageous when heavy metals, nutrients and degradation-products of organic matter have been remobilised from the sediment and accumulated in the near bottom layer.

6.2.3 Water level

The water level of lakes is generally dependent on meteorological conditions in the past, whereas the time and the volume of the discharge from a reservoir can - within certain limits - be determined even prospectively according to demand. Another important difference between natural lakes and man-made reservoirs, which are used for drinking water supply or low flow augmentation of tail waters, is the fluctuation of the water level. This impedes shoreline vegetation and growth of rooted macrophyte, and consequently there is no chance for the establishment of a rich benthic biocenosis, which is a prerequisite for a good fish production.

6.2.4 Ecological and economic functions

Before elaborating the typology of water bodies and the potential for human utilization, it should be emphasised that natural lakes and to a certain extent also man-made lakes are constituent parts of the natural landscape and aquatic biotopes with important ecological functions. So they possess a value of their own, independent of the usefulness for human purposes.

On the other hand, dams and reservoirs are man-made constructions, designed and operated according to one or several special duties within the task of water quality and water quantity management.

This clarification seems necessary for finding a proper balance of diverging interests e.g. between environmental protection versus anthropogenic exploitation. To what extent can we use our water and water bodies without detrimental effects on the aquatic environment? This question, namely the definition of tolerance limits, is one of the most important and most difficult questions as well in theoretical ecology as in practical water quality management.

6.2.5 Mixing regime (vertical stratification)

Temporal stratification is the most important characteristic feature of deep lakes and reservoirs. It has great influence on the distribution of algae, the oxygen budget (Fig. 6.1) and remobilization of substances from sediments.

Figure 6.2 shows, for example, the water quality in Bigge-Reservoir - moderately eutrophic body with a storage volume of about 178 x 10^6 m^3 and a mean depth of ~ 20 m - during summer stagnation.

Within the thermocline, situated between 5 to 10 m below surface, the oxygen-saturation shows a minimum. The hypolimnetic oxygen content is not depleted as in the highly eutrophic Möhne-Reservoir (see Fig. 6.1). Only near the bottom is a marked oxygen decrease observed. Oxygen and pH are elevated in the trophogenic layer due to algal photosynthesis, which also leads to a carbon dioxide depletion.

The phytoplankton is obviously dominated by diatoms, as can be concluded from the epilimnetic silica depletion. Manganese and iron, as well as ammonia, have been remobilised from the sediment and accumulated in the bottom layer. The intermediate ammonia peak and the oxygen minimum in the metalimnion are indicative for microbial degradation processes, going on just below the trophogenic layer, where typically a bacterial peak can be observed. The final degradation takes place in the tropholytic layer, particularly in the sediment-water-interface.

The temperature profile, the oxygen concentration, the chlorophyll content (measured by in vivo fluorescence) and the turbidity in different depth of the Lister-Reservoir are shown in Fig. 6.3.

Most interesting is the comparison of the oxygen-, chlorophyll fluorescence- and the turbidity curve. The turbidity peak is situated within the metalimnion, between oxygen-poor and oxygen-rich water, where we found high concentrations of manganese oxidizing bacteria, exploiting the solubilized manganese accumulated in the anaerobic hypolimnion.

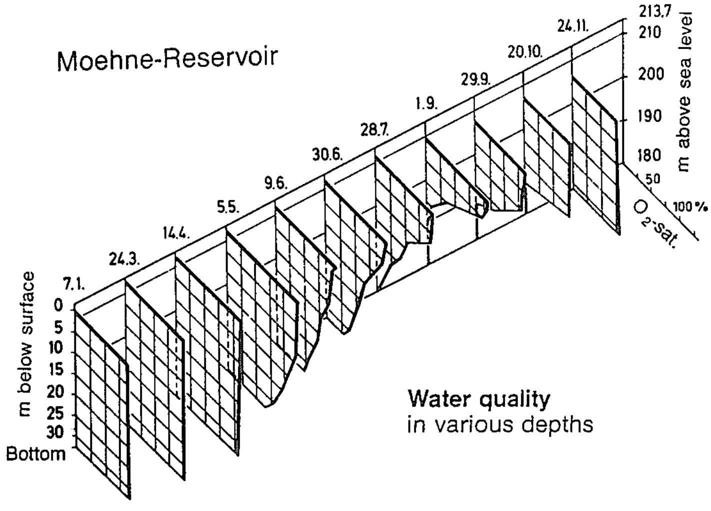


Fig. 6.1 O_2-saturation in Möhne-Reservoir in the course of the year

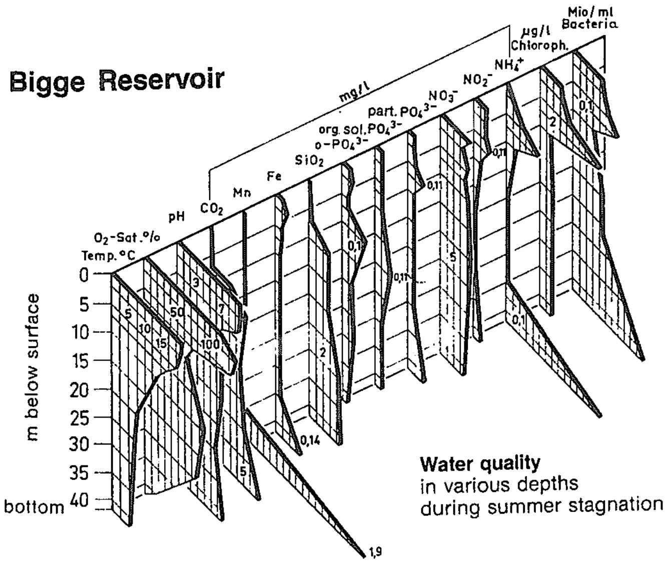


Fig. 6.2 Water quality in Bigge-Reservoir during summer stagnation

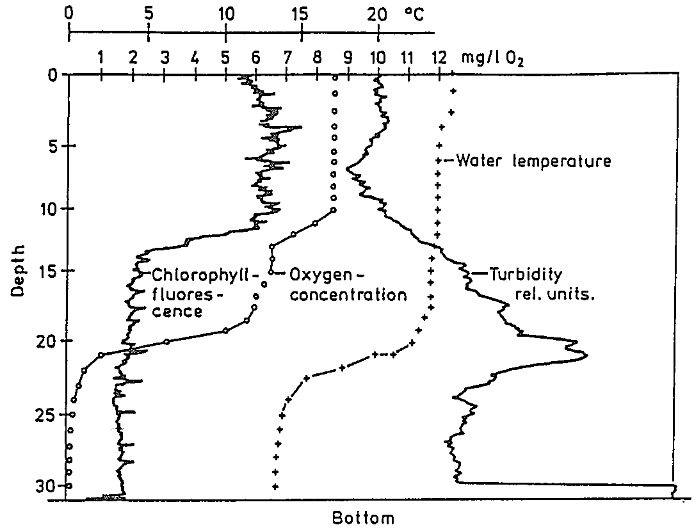


Fig. 6.3 Temperature-, oxygen- chlorophyll fluorescence- and turbidity profiles in Lister-Reservoir

6.2.6 Horizontal quality gradients

Water quality is not only changing with depth, but there are also pronounced horizontal quality gradients, especially in long and narrow reservoirs, where the water quality improves considerably between inflow, pre-impoundment basin and the deeper parts of the main basin near the dam (Fig. 6.4).

A comparison of the weighted mean inflow concentration (computed from the total annual loading of all tributaries) and the outflow concentrations reveals that the reservoir systems act as nutrient sinks and as self purification reactors.

The retention of phosphorus in the reservoirs, mainly due to sedimentation of algae and biogenic precipitation of calcit particles, amounts to about 70-80%. The decrease of nitrogen-compounds (~40%) can be ascribed primarily to denitrification.

The decrease in COD is also observed in eutrophic reservoirs, where organic matter is produced temporarily by algal photosynthesis. The total budget, however, shows that on a multi-annual basis secondary pollution by in-lake-bioproduction is over compensated by the degradative capacity.

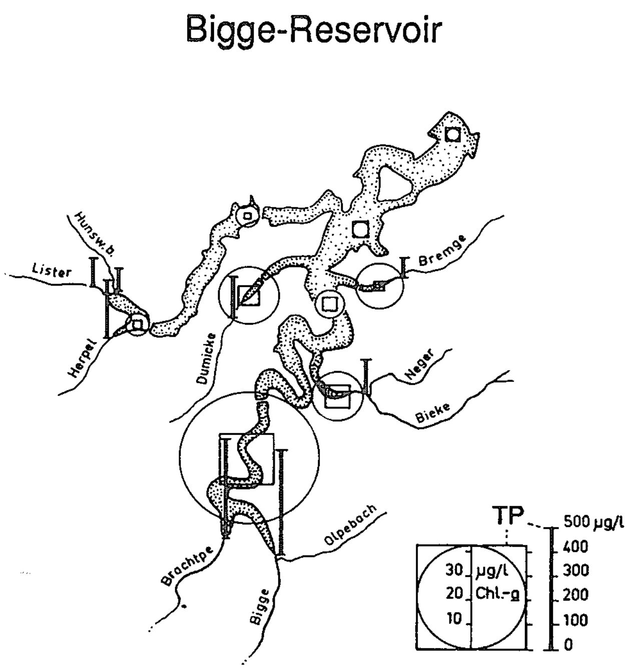


Fig. 6.4 Phosphorus (TP) in tributaries (I), and different parts (and prebasins) of Bigge-Reservoir (□) and related chlorophyll-concentrations (○)

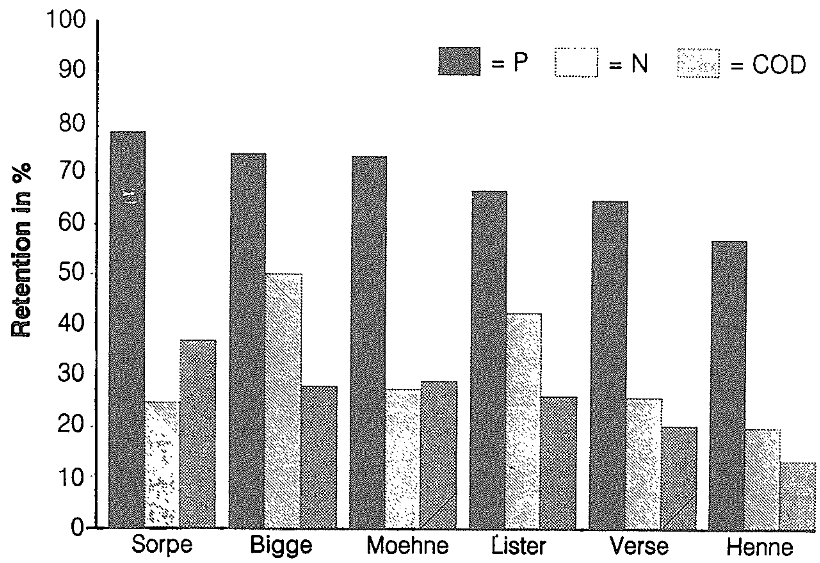


Fig. 6.5 Nutrient retention and COD-decrease in RRA-Reservoirs (Mean values 1982-1992)

6.2.7 Interaction of water quantity and water quality

Water depth and the hydraulic retention time are the most important characteristics determining water quality. The water depth, geomorphologic and climatic conditions (wind exposition) determine the stratification pattern (mixing regime). The onset and duration of stagnant periods (in both summer and winter) has great influence on the oxygen budget and related water quality problems. The hydraulic retention time is important for the exploitation of nutrients, trophic tolerance, self-purification processes and secondary pollution effects [2].

In this respect I am particularly interested in river impoundments, "limnological hybrids" that are "no longer rivers but not yet lakes". They show features of rivers with lotic aspects, population dynamics between growth and wash-out, as well as temporal stratification, interaction of phyto- and zooplankton, sedimentation in lentic parts and other characteristics of lakes [3].

Figure 6.6 shows the spatial inhomogenity or "patchiness" of the phytoplankton distribution in Lake Baldeney, one of the Ruhr River impoundments. The theoretical water retention time is 33 hours at average runoff (75 m^3/s) and 118 hours at low flow (20 m^3/s).

In the upper part of the lake, especially at the inflow of tributaries where the algal concentrations are diluted, we find relatively low chlorophyll values. In the middle part of the impoundment the course of the old river bed is reflected by the chlorophyll gradient between right and left banks. Local accumulations of algae are found in the shallow areas of the left bank where as the Ruhr River, with comparatively low algal concentrations, flows along the right river bank.

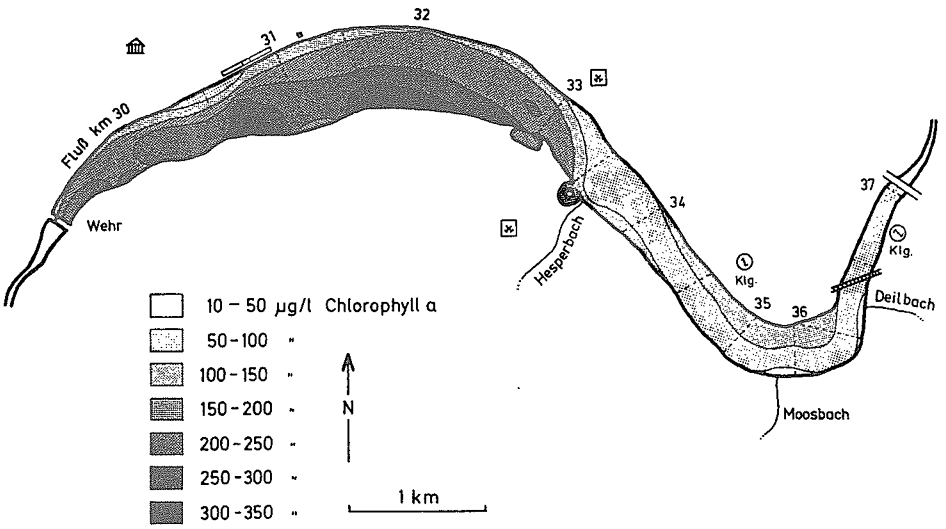


Fig. 6.6 Distribution of phytoplankton (measured as in vivo-chlorophyll fluorescence) in Lake Baldeney

Figure 6.7, shows the relation of phosphorus and chlorophyll, the most important parameters to describe cause and effect of eutrophication. The regression line is based on the early investigations of Sakamoto [4] in Japanese lakes. Vollenweider & Dillon [5] added more data without changing the Sakamoto regression line. More data have been contributed from the results of the OECD Eutrophication Project on Reservoirs and Shallow Lakes [6], which led to the dotted regression line. The crosses indicate the current trophic situation of our Westphalian reservoirs. Obviously they fit well into the OECD-regression. In contrast, this is not the case with Ruhr River impoundments. In relation to their phosphorus concentrations they produce two orders of magnitude less chlorophyll than predicted by the OECD-model.

The reason for this is the limited water retention time in the impounded river stretches, which does not allow full exploitation of the nutrient supply for algal growth. The algal growth potential (AGP) is much higher, as can be seen, when the water is incubated for several days under standard light and temperature conditions.

This diagram shows that water quantity or flow (determining either growth or flushout of algae) and water quality (chlorophyll as measure of algal biomass) are closely interrelated.

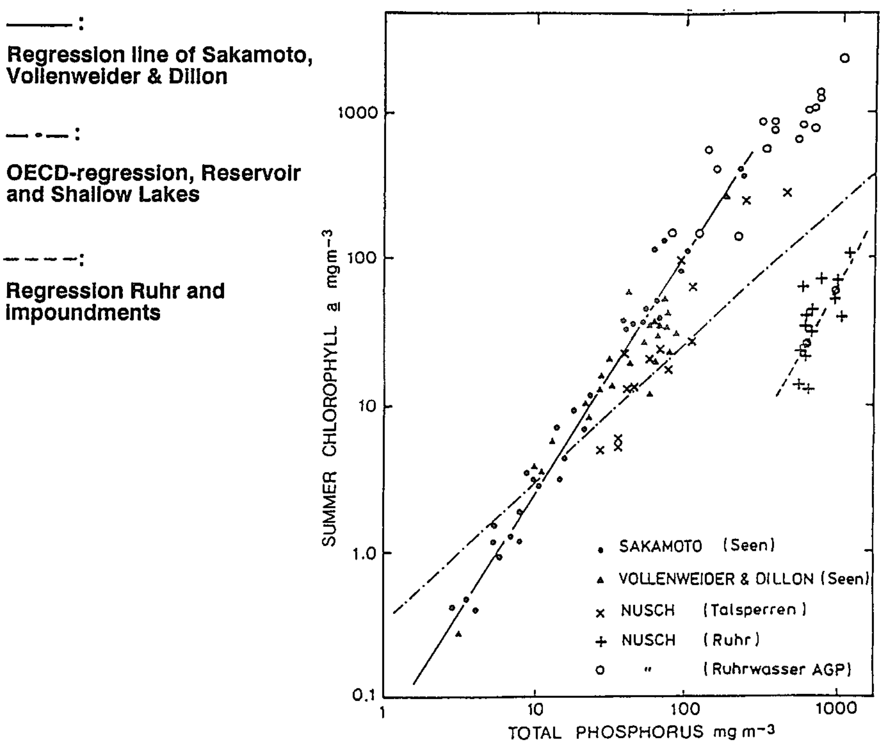


Fig. 6.7 Phosphorus (TP) and chlorophyll content in lakes, reservoirs and the impounded Ruhr River

The relation of water quantity and quality is often pragmatically simplified in the oft-used sentence "dilution is no solution for pollution". This is true if the pollution load is considered. In the case of toxicity, however, where effective concentrations of toxicants are important for aquatic life, dilution may be helpful.

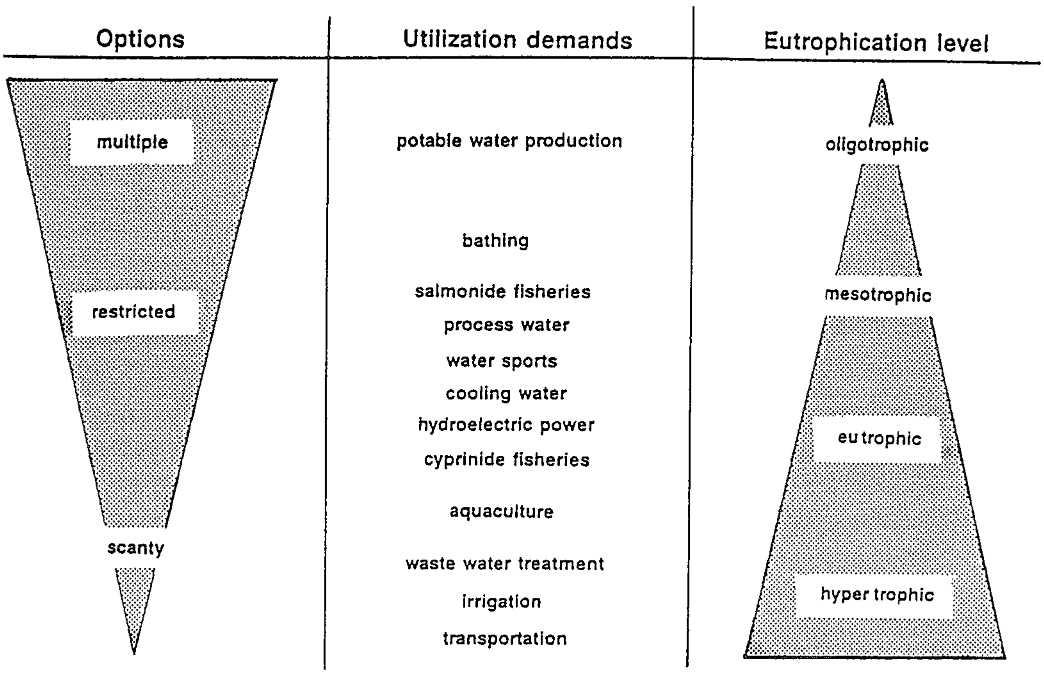
It has become apparent, that the water quality of our lakes and reservoirs is mainly determined by primary production and microbial degradation. Abiotic factors, such as water retention time, irradiance, temperature gradients, input of nutrients, organic and toxic pollutants have an influence on the basic metabolic process - namely trophicity and saprobity.

Problems arise, when the intensity of bioproduction exceeds the degradation capacity, as it is the case in hypertrophic waters, which are no longer, or only to a very limited extent, suitable for human use.

6.3 UITILIZATION OF WATERS IN RELATION TO EUTROPHICATION

Bernhardt and Clasen [7] related certain uses to different levels of eutrophication (Table 6.1).

Table 6.1 Options for water use in relation to eutrophication (after Bernhardt & Clasen, 1982; modified)



Oligotrophic water is best suitable for drinking water, mesotrophic waters are good for salmonids, a higher productivity is needed for cyprinid-fisheries and aquaculture.

Slightly eutrophic waters are tolerable for most recreational activities; highly eutrophic water, however, with excessive water blooms or growth of macrophytes are not good for bathing or water sports (e.g. rowing, sailing). Water rich in nutrients are good for irrigation, while for process and cooling water a slight eutrophication is tolerable.

Planktonic algae are no problem for hydroelectric power generation, excessive macrophyte growth, however, is often deleterious because of clogging of intake screens.

The treatment of waste water for instance in stabilising ponds and polishing lagoons, is possible and even particularly efficient in hypertrophic systems. Lastly, cargo can be transported by ship even in waters of worst quality.

The sequence of high to low quality uses relative to different eutrophication levels considered optimal or tolerable for special purposes maybe questioned. The essence is that the number of options, i.e. the multiple use potential, decreases substantially with an increasing degree of eutrophication.

6.4 QUALITY RELATED PROBLEMS WITH REGARD TO SPECIAL WATER USES

The most sensitive and irrevocable option of human water is the preparation and consumption of drinking water. As I pointed out before, one should bear in mind that in some arid countries the available quantity problems may arise, when mass developments of planktonic algae occur and the technology of drinking water production is not adapted. Some algal species are notorious for their production of taste and odour compounds. Clogging of filters by bulky and/or slimy algae is another serious problem for the processing of eutrophic raw water.

Algogenic organic matter, in particular acidic polymers with vicinal hydroxyl- and carboxyl-groups, influence flocculation with trivalent metal oxide hydroxides. At higher concentrations (>1 mg/l DOC) electric destabilization and aggregation of flocs is impaired [8]. Water works using iron or aluminum salts for flocculation, have experienced the following problems:

- increase in flocculant residues in the filtrate
- inhibition of elimination of turbid matter
- impediment of disinfection due to:
    - reduction of chlorine to chlorite
    - increase in chlorination by-products
    - increase in chlorine consuming processes
- consequence: re-growth of microorganisms in the drinking water distribution system

Ammonia is of great concern to the waterworks because it may cause disinfection problems. Ammonia is also deleterious for fish life, when elevated concentrations (due to impeded nitrification in winter) coincide with elevated pH-values (due to algal photosynthesis). This fatal conversion of ionized ammonia (NH_4) to toxic NH_3 occurs sometimes in Ruhr River impoundments in late spring and leads to fishkills, when other causes, (e.g. oxygen-depletion and/or -supersaturation, infections, spawning fatigue) contribute to the toxic stress.

Moderate eutrophication is favourable for fisheries. Figure 6.8 shows the gross yield of fisheries in the RRA reservoirs. As the production of fish, the final link of the aquatic food chain, is closely related to primary production, it is not surprising that in the oligotrophic Fürwigge-Reservoir only about 5 kg/ha fish (salmonids) are caught. In mesotrophic Verse-Reservoir the annual catch is much lower than in the eutrophic reservoirs. The extraordinary high production in Sorpe-Reservoir is not only due to the fertility of the water but also to the high volume/area-ratio and the activity of the local fisherman. The commercial value of all fish caught in Ruhr-reservoirs amounts to about US$500,000 per year.

The costs for stocking young fish, part of which are produced in our own hatchery situated at the Möhne-reservoir, are equivalent to about US$125,000. The expenditure for stocking is compensated by the income from selling angling licenses by more than 100%.

Excessive eutrophication is a hazard to fish life, because in the upper water layers pH often rises to values of 9 and even more (due to photosynthetic CO_2-consumption) whereas in the lower water layers the oxygen concentration decreases to almost zero (due to microbial degradation or organic matter). The fish, having little choice between getting cauterized or suffocated, gather in an intermediate water layer, as shown by echographs (Fig. 6.9).

Most interesting is the distribution of roach in the upper metalimnion and salmonid whitefish (Coregonids) in the lower metalmnion. Obviously *Coregonus albula*, known as cold stenothermic, avoids the warmer water, even if it contains more oxygen.

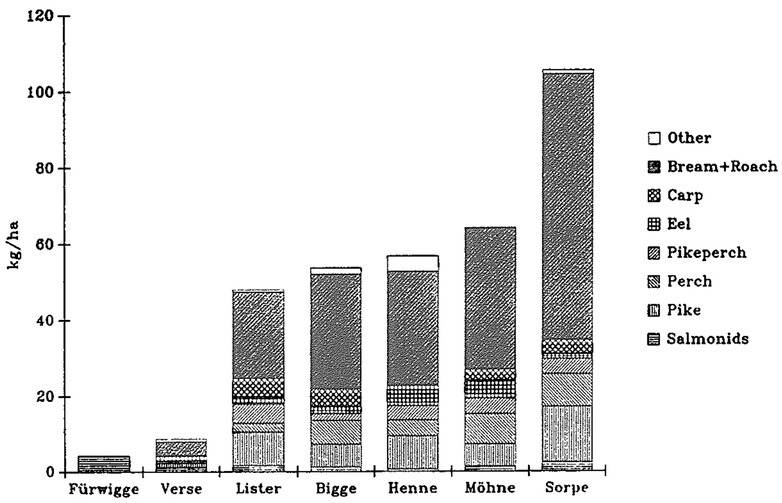


Fig. 6.8 Annual catch of several fish species in RRA-reservoirs (Mean gross yield per hectare, 1976-1986)

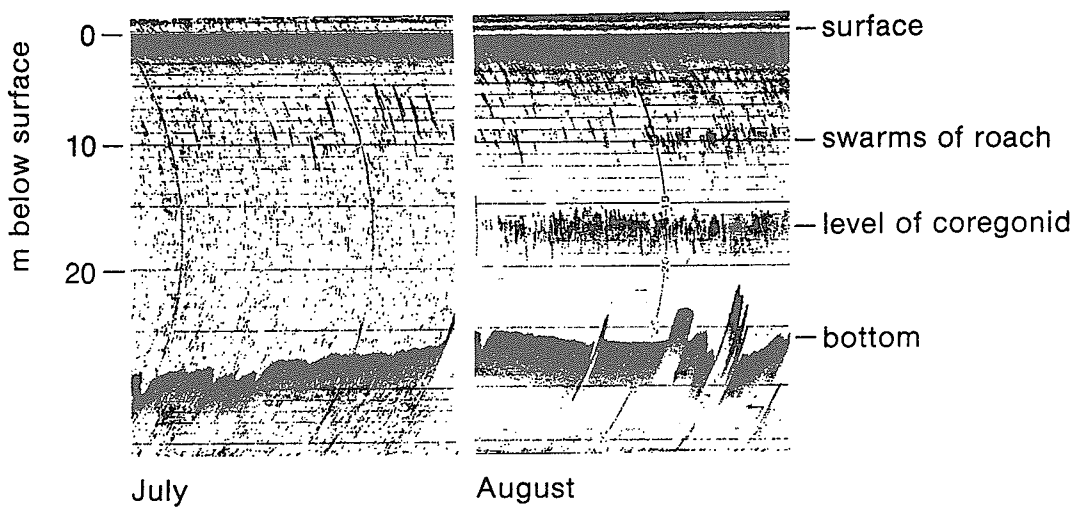


Fig. 6.9 Fish distribution in Möhne-Reservoir during summer (Echographs)

The consequences of eutrophication and related impairments of water uses are summarised as follows (Table 6.2):

Table 6.2 Consequences of eutrophication

- **problems for drinking water supply** (e.g. taste and odour, colmation of filters)
- **impediment of flow** (e.g. by weedage)
- **impairment of hydroelectric power generation** (e.g. by clogging of screens)
- **endangering of fish populations** (e.g. by high pH and low oxygen concentration)
- **endangering of birds and mammals** (e.g. by algal or bacterial toxins (botulism))
- **decrease of recreational value** (e.g. by weedage, allergogenic algae)
- **biocenotic changes** (e.g. salmonids -> cyprinids)
- **siltation, warping** (enhanced by weedage and algal production)

6.5 QUALITY STANDARDS AND GUIDELINES

It would be senseless to cite all the national and international standards and directives since they refer mostly to drinking water quality (e.g. the WHO Guidelines for Drinking Water Quality (1984) [9]. Only a few notifications on raw water quality of surface waters intended for the abstraction of drinking water are officially released, e.g. EC Surface Water Directive (75/440/EEC) [10].

Table 6.3 with the quality objectives for the River Ruhr, as it was agreed by Ruhr River Works Committee [11], may give a first impression of the quality standards which shall be achieved in the years to come. The phosphate concentration of 0.45 mg/l, equivalent to about 150 μg/l soluble P is a very ambitious goal, but it is necessary to avoid mass developments of planktonic algae, which still cause problems for the drinking water preparation.

Pesticides and herbicides are not tolerated in drinking water in concentrations exceeding 0.1 μg/l (0.5 μg/l total sum) according to the EEC-Drinking Water Standard. These rather low values, which are far below toxicological relevance, should not be exceeded in raw water either, since those substances and their metabolites cannot be eliminated by customary means.

This is also true for some synthetic chelators, especially for EDTA, a non degradable compound used in industrial cleaners which has been found in considerable concentrations in drinking water [12]. In surface water these stable synthetic chelators are undesirable because of their ability to remobilize heavy metals from sediments. A less harmful alternative might be NTA, because it will be substantially degraded in waste water treatment plants and in surface waters [13].

Targets of Ruhr water quality as postulated
by the study group of Ruhr water works (AWWR)

no.	parameter		unit	target: medium-term	target: long-term	standards for potable water (Trinkw.-V. v. 22. 5. '86)
1	cadmium	Cd	µg/l	2	1	5
2	chromium	Cr	µg/l	50	30	50
3	manganese, dissolved	Mn	µg/l	50	30	50
4	nickel	Ni	µg/l	40	30	50
5	ammonia	NH_4	mg/l	0,5	0,20	0,5
6	nitrate	NO_3	mg/l	35	35	50
7	chloride	Cl	mg/l	100	100	—
8	phosphate, dissolved	P	mg/l	0,20	0,15	—
9	DOC	C	mg/l	6	4	—
10	AOX	Cl	µg/l	30	15	—
11	anionic detergents	MBAS	mg/l	0,2	0,15	} 0,2 (11–12)
12	nonionic detergents	BIAS	mg/l	0,2	0,15	
13	trihalogen methane		µg/l	5	2	(25)
14	tetrachlorethene		µg/l	5	3	} sum ≤ 25 (14–17)
15	tri-ethen chloride		µg/l	5	3	
16	1,1,1-trichlorethane		µg/l	1	1	
17	dichlormethane		µg/l	2	2	
18	carbon tetrachloride		µg/l	1	1	3
19	atrazine		µg/l	0,08	1)	0,1
20	simazine		µg/l	0,04	1)	0,1
21	terbuthylazine		µg/l	0,04	1)	0,1
22	NTA		µg/l	50	25	—
23	EDTA		µg/l	50	25	—
24	coliform bacteria		100ml⁻¹	15000 2)	5000 2)	0

1) further reduction
2) geometrical annual average

Table 6.3 AWWR Quality Objectives for the Ruhr River

Polycyclic aromatic hydrocarbons (PAH), partially known as carcinogenic, are not relevant for raw water quality since they are adsorbed on particles and easily removable.

It was already pointed out that ammonia is of great concern for the potable water supply. In winter time, when the nitrification is impeded by too low a water temperature, the ammonia concentrations become elevated, especially in times of low flow. The A3-Imperative Value of the European Guideline for Surface Water (3.1 mg/l NH_4-N) can mostly be met throughout the year.

The A2-I-Standard of the EEC-Directive, however, cannot be met at temperatures >10 °C if the flow rate is lower than 50 m^3/s (Fig. 6.10). This diagram is shown to demonstrate how water quality is dependent on abiotic factors, such as temperature and water flow. Decrease in concentration by dilution, namely by low flow augmentation with reservoir water, is only possible to a limited extent depending on the actual capacity (available volume) of the reservoirs.

Further improvement of the performance of waste-water treatment plants is hardly achievable as the temperature dependence of nitrification cannot be abrogated. At any rate the uncontrolled inflow of cold groundwater into the sewerage should be avoided to maintain the elevated temperatures of raw domestic sewage as long as possible.

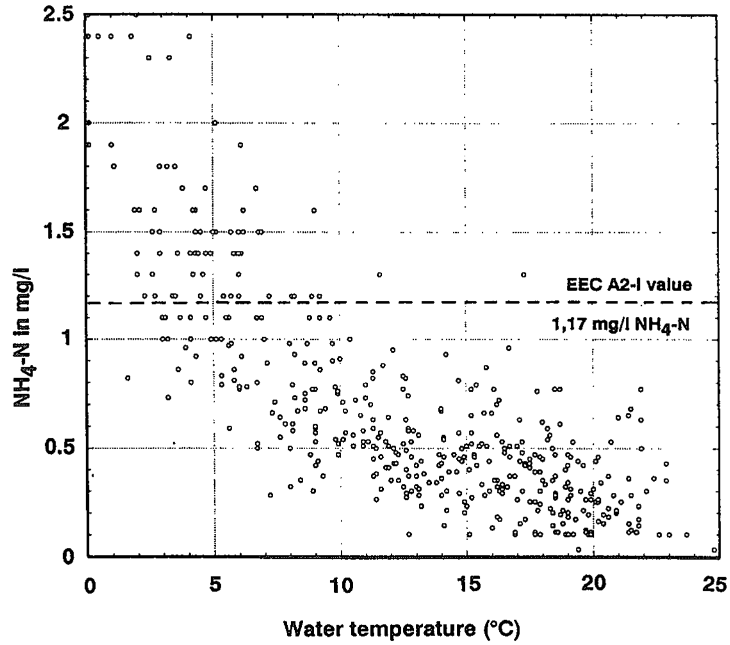


Fig. 6.10 Ammonia concentration (NH_4-N) in the Ruhr River in relation to water temperature (°C) at flow 25 - 50 m^3/s

6.6 WATER QUANTITY AND WATER QUALITY MANAGEMENT IN THE RUHR RIVER BASIN

Most of the examples of quality related problems of human use of waters are taken from experience with water quality monitoring and water and waste management at the Ruhr River, strained between utilization and protection of waters.

The River Ruhr, a relatively small river (it is only 217 km in length) flows through some of the most densely populated industrial areas of the Federal Republic of Germany. Over 5 million inhabitants are provided with drinking water abstracted from the Ruhr River.

Even regions outside the river basin, for instance the Emscher/Lippe Industrial District, are supplied with water from the Ruhr, which is pumped after treatment in the waterworks in the Ruhr valley across the watershed.

That is why a large proportion of the annually abstracted water does not flow back into the Ruhr River but is discharged as waste water in adjacent river basins. The water loss - in some years more than 400×10^6 m^3/a - is compensated by 14 reservoirs with a total storage capacity of about 470×10^6 m^3. These reservoirs, dams in the valleys of the Westphalian mountains, are operated primarily for the purpose of low flow augmentation to compensate for the water export [15].

According to its legal status - the former law dating from 1913, was amended in 1990 - the Ruhr River Association has to guarantee a minimum runoff of 15 m^3/s below the city of Essen even during dry periods. This obligation can only be fulfilled if the available storage capacity of the reservoirs systems is utilized according to a well designed operation plan optimized by means of mathematical models based on data from long term time series of runoff and inflow into the reservoirs. Several scenarios are taken into account, namely times with normal rainfall and runoff, critical dry periods and flood times.

In the last years, especially during flood periods, when the hydraulic retention in the reservoir system contributed towards preventing flood damage downstream, the demand for fast and comprehensive information became urgent. So RRA implemented a new digital data acquisition and transmission system based on automatic microelectronic recordings, coded data transfer by public telephone lines, and computerised evaluation and documentation. (For details see [16])

Apart from providing drinking water for the population the Ruhr River has also to receive the waste water of more than 2 million inhabitants and from industry in the drainage basin [17].

Figure 6.12 shows more than 100 waste water treatment plants spread over the area. Nearly all of them are operated biologically. Tertiary treatment is carried out in drainage basins of reservoirs and in urban areas with impoundments endangered by eutrophication.

The river impoundments - Lake Baldeney near Essen for instance, well known from the numerous publications of Imhoff and co-workers [2, 3, 18, 19], have been built in the middle and lower stretches of the Ruhr River. They were originally designed to promote self purification and to generate hydro-electric power. However, today the amenity value for the population and the facilities for water sports are obviously of outstanding importance.

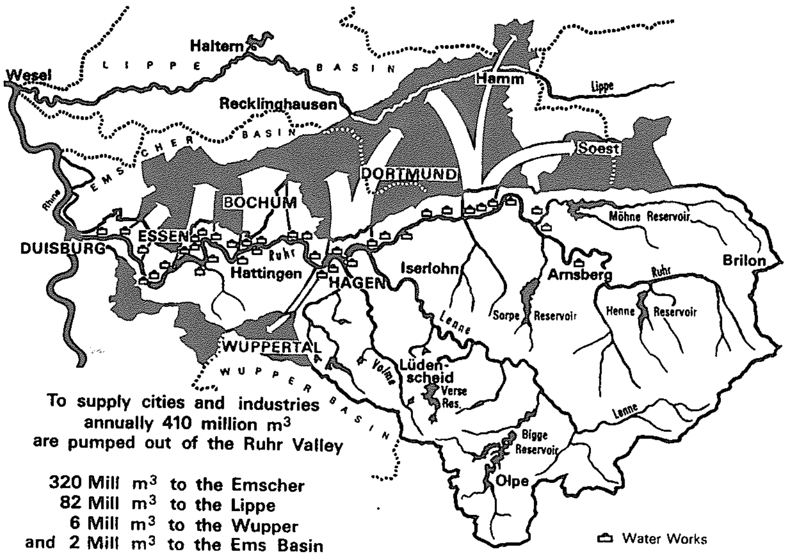


Fig. 6.11 Water supply in and out of Ruhr River basin

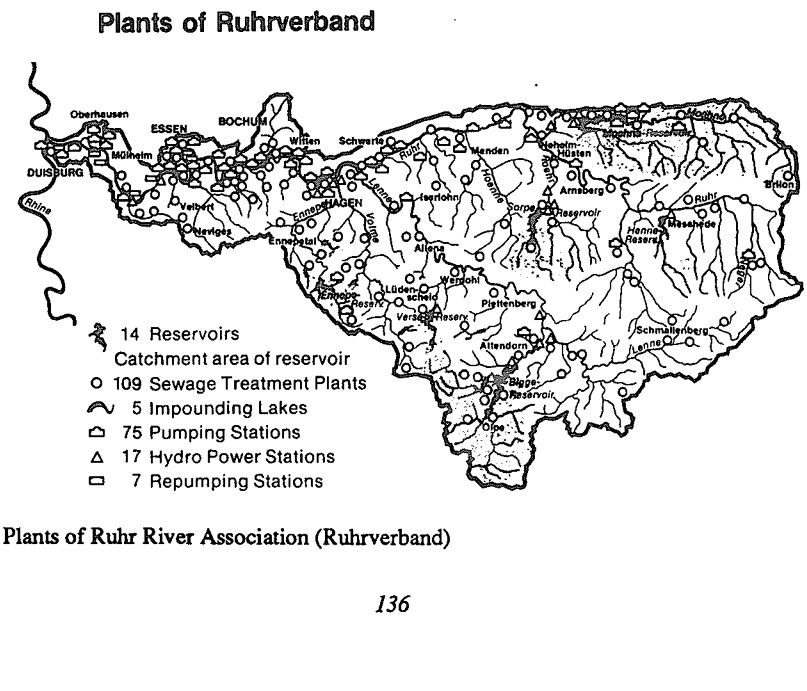


Fig. 6.12 Plants of Ruhr River Association (Ruhrverband)

6.7 PROBLEMS ARISING FROM COMPETING FUNCTIONS WITH SPECIAL REFERENCE TO RECREATIONAL ACTIVITIES

As mentioned already, the prime function of the Ruhr Reservoirs is low flow augmentation. Flood control, power generation and fish production are supplementary but of considerable economic value. Growing importance refers to the recreational activities in, on and at the waters [20].

Since the RRA-reservoirs are situated in a beautiful landscape in the vicinity of a densely populated industrial region, and the leisure time of the working people is becoming more and more extended, public pressure is exerted on the Ruhr River Association to allow water-bound recreation on the Westphalian reservoirs.

Table 6.4 shows the recreational activities in and at the Ruhr Reservoirs and impoundments. Some of the intended uses are compatible, others are not, or only reconcilable with certain conditions, precautions and regulations.

Some examples of the most important coinciding use patterns shall be discussed here. For instance: the alternative use of water, either for bathing or as recipient of wastewater, is obviously exclusive for hygienic reasons unless more elaborate wastewater treatment is employed.

A Guideline of the European Community (76/160/EEC) gives standards for the use of natural water bodies for bathing. Bathing sites with more than 5000 guests/day have to be examined for microbiological and physic.-chemical parameters indicating pollution or eutrophication. Most important are the Imperative Standard Limits (I-values) of 10000 Total Coliforms, 2000 Fecal Coliforms, 0 Salmonella in 100 ml water.

The eutrophication level is limited by pH-boundary-values <9 and Secchi-disc transparency >1 m. These values, indicative for moderate eutrophication, shall minimize the risk of heavy water blooms, particularly of cyanobacteria, which are notorious for the production of allergogenic toxins [21-23]. High mineral of biogenic turbidity is of concern for reasons of safety because rescue-measures may be impeded.

When bathing cannot be allowed in the open water, in some cases public on-shore or indoor bathing-facilities are available - an example of compensation for prohibited functions.

Surfing is, surprisingly for non-experienced surfers, considered a water sport without direct body contact and is not addressed by the EC-Bathing Water Guideline.

The hygienic deterioration of water quality (pathogenic germs, fecal pollution) allegedly caused by swimmers is, in my opinion, often exaggerated. More serious are problems of shore line protection, disturbance of water fowl and fish and stirring up of sediments leading to excessive turbidity.

Recreational activities on reservoirs and impoundments in the Ruhr drainage basin

type of usage	Verse	Moehne	Sorpe	Bigge/List.	Henne	Ruhr-Lakes
angling	/	○	○	○	○	○
bathing	—	○	○	○	○	—
diving	—	○	○	○	—	—
rowing	—	○	○	○	○	○
sailing	—	○	○	○	○	○
surfing	—	○	○	○	○	/
motor yachting	—	—	—	—	—	/
navigation	—	○	○	○	○	○
camping	—	○	○	○	○	○

○ = allowed
/ = restricted
— = not allowed

Table 6.4 Recreational activities at the RRA-reservoirs and impounded lakes

Camping is one of the most popular recreational activities on lake shores. At the RRA reservoirs it is allowed only on special sites with adequate infrastructure, i.e. sanitary facilities, waste water sewerage, litter boxes, barbecue places etc..

Angling and professional fisheries often conflict with yachting, sailing and surfing, particularly when hook and line or nets are entangled. In some cases waterfowl has been caught by hook and line "fishery". The hunting or dispel of grey heron or king fisher and the introduction of foreign fish species (e.g. grass-carp) by anglers does not comply with wild life conservation.

Nor does yachting, canoeing or angling if mating or breeding activities of water fowl are disturbed. It has been reported, that winter fish kills under ice cover are promoted by ice skaters when fish metabolism is enhanced after disturbance of the winter rest.

Not only are fish influenced by the water quality, but, water quality is also influenced by fish (and fisheries). Intensified fish production in net cages and excessive baiting e.g. for carp, can lead to local accumulations or organic materials.

Planktivorous fish reduce the zooplankton's grazing pressure on phytoplankton. That is why a professional fisherman is engaged in catching Coregonids (planktivorous salmonids) in order to prevent the so called "ichthyo-eutrophication" in other words enhancement of algal production by planktivorous fish.

The coexistence of anglers and professional fisherman is often at stake when anglers destroy the nets and weir baskets to discourage the professional competitor.

Overfishing is prevented by restricted issue of angler licences dependent on productivity, surface area and length of shoreline (Table 6.6).

Motor-yachting is not allowed in RRA-reservoirs to prevent oil spills and excessive wave action, which might destroy the shore line protection and splash fish spawn or -brood ashore. The only motorboats permitted are for supervisory tasks, including water sampling for quality monitoring, rescue and passenger transport.

Passenger ships are specially designed with tight containers (for waste collection, oil spill prevention) and bow ramps (dampers). Stationary gangways are not suitable because of the fluctuating water level.

The water level and thus the navigable surface area as well as the living space for fish is largely reduced during the summer. The number of sailing boats has to be controlled by selling licences. An areal density of up to 5 units per hectare is considered to be tolerable (Table 6.5).

Flood control and power generation is deleterious to fish passing the turbines and the bottom outlet. This has caused severe fish kills at the Möhne and Bigge reservoir. For the time being we have no means to prevent fish from getting into the suction current. Electric repellors have not been successfully tested yet.

The impeded fish migration by the weir is compensated by stocking. Fish stairs have been constructed beside a boat slide to help fish as well as canoeists to overcome the barrier of different water levels.

Sailing and surfing on RRA-reservoirs (1987)
(acc. to Imhoff & Mantwill 1988)

Reservoir		Henne	Moehne	Sorpe	Bigge	Lister	Total
Surface area	(ha)	210	1037	330	868	168	2613
Sailing area	(ha)	199	822	330	670	106	2127
Sailing boats (annual licences)	(n)	148	891	427	744	107	2317
Surf-boards (annual licences)	(n)	105	2439	1030	705	436	4715
Areal density	(n/ha)						
Sailing boats		0,74	1,08	1,29	1,11	1,01	1,09
Surf-boards		0,53	2,97	3,12	1,05	4,11	2,22
Total		1,27	4,05	4,41	2,16	5,12	3,31

Table 6.5 Sailing and surfing on RRA-Reservoirs 1987

Reservoir	Volume 10^6 m^3	Area km^2	Shoreline km	Licenses annual	Anglers per km^2	per km
Fuerwigge	1,76	0,18	3,9	6	33	2
Verse	32,8	1,71	16,7	147	86	9
Henne	38,4	2,10	17,8	455	217	26
Sorpe	70,6	3,34	19,5	659	197	34
Moehne	134,5	10,40	39,0*)	1 482	143	38
Bigge M.-B.	150,1	7,14	49,9	1 275	179	33
Bigge P.-B.	5,3	0,88	11,1	417	474	38
Lister	21,6	1,62	12,2	380	235	31
Total	455,0	27,37	170,1	4821	176	28

*) 24 km shoreline restricted for wild life protection

Table 6.6 Angling licences for RRA-Reservoirs 1987

Lake Kemnade, a Ruhr River impoundment, finished in 1979, was primarily designed for recreational purposes. Here we could profit from the experience gained at the older reservoirs as far as the management of recreational activities is concerned. Guiding principles are listed in Table 6.7.

Example for compensation: If waste water discharge excludes in lake-bathing attractive facilities are provided on shore or indoors.

Examples for risk minimization and provision for possible future risks:

The wastewater from a large treatment plant (300,000 inhabitant equivalents) has to be discharged into an almost stagnant bay (yacht-harbor). The wastewater has to be treated biologically and chemically to achieve high standard purification. Additionally the effluent is given a final treatment in polishing lagoons.

In case of water quality problems it is provided to flush the narrow bay with diverted Ruhr water, particularly in order to reduce NH_3-toxicity. Areas for later sediment disposal had to be provided before the lake was impounded when in future times dredging may become necessary.

Guiding principles for the
management of recreational activities

- **maintainance of prime function** without impediment by secondary usage
- **setting of priorities**
  in case of mutually excluding functions
  (e. g. bathing ↮ waste water discharge)
- **reconciliation of competitive functions**
  by guidelines or regulations to prevent excessive usage
  (e. g. limitation of boat per ha surface area;
  limitation of angler licences)
- **compensation of prohibited functions**
  (e. g. boat slides and fish stairs at weirs, indoor instead of inlake bathing)
- **consideration of ecological interests**
  (e. g. protected areas for wild life
  prevention of over-fishing, seasonal limitations)
- **consideration of present and future risks**
  (e. g. resulting from toxicity, availability of sediment disposal areas)
- **provision of adequate infrastructure**
  (e. g. parking areas, sanitary facilities, controlled waste discharge)
- **separation of conflicting activities**
  (e. g. foot path versus cycle tracks,
  bathing sites versus surfing area)
- **assignment of responsibility** (for proper management, coordination and operation)
  (e. g. foundation of non-profit associations)

Table 6.7 Guiding principles for the management of recreational activities

Examples of separation

Footpaths and cycle tracks are separated to prevent collisions, roller skaters prefer one of the two ways dependent on their skill and velocity. Special areas, designated for wildlife protection, in particular for water fowl and amphibia, are not accessible to the public.

6.8 CONCLUSIONS

The reservoirs and impoundments in the drainage basin of the Ruhr River are good examples of multiple use of waters. Multiple use patterns, however, often cause problems and conflicts between different competing functions.

Experience with integrated water quantity and water quality management in the Ruhr River basin shows, that even in a densely populated industrial area, some of the problems can be solved or at least minimized. Even use patterns are regarded as non compatible, e.g. drinking water supply and waste water discharge, may be tolerable, if high technological standards are applied - for drinking water production as well as for waste water treatment.

We do not neglect the fact the solutions developed by means of large financial efforts within decades of river basin management might not be appropriate for the urgent problems under the constraints in developing countries.

The story of the Ruhr River Association, its successes (and failures) may, however, serve as an example of the problems to cope with and proved practical strategies to keep, or make, lakes and reservoirs suitable for human use.

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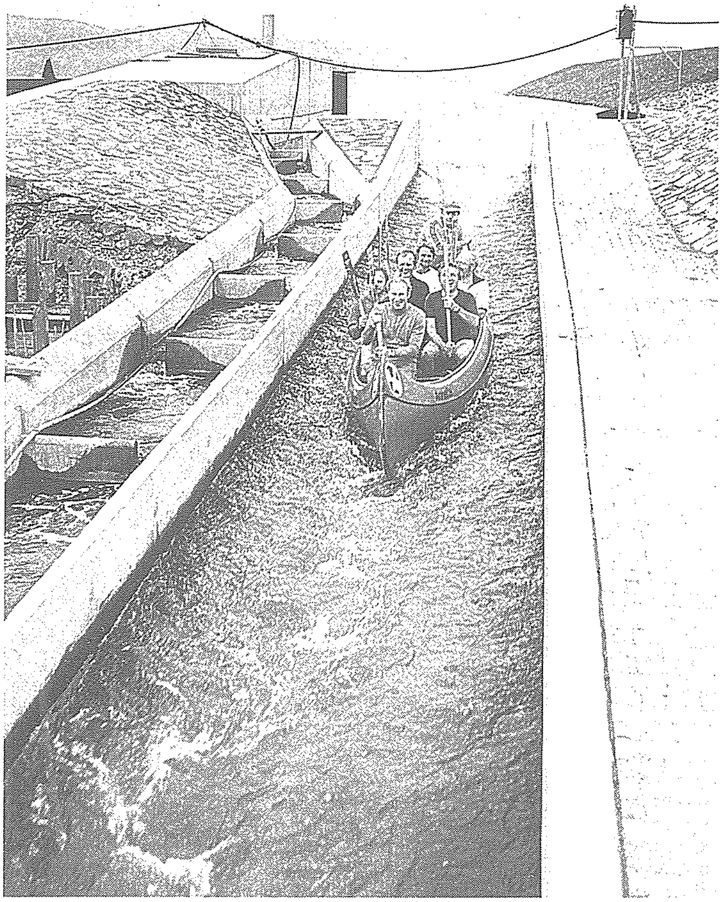
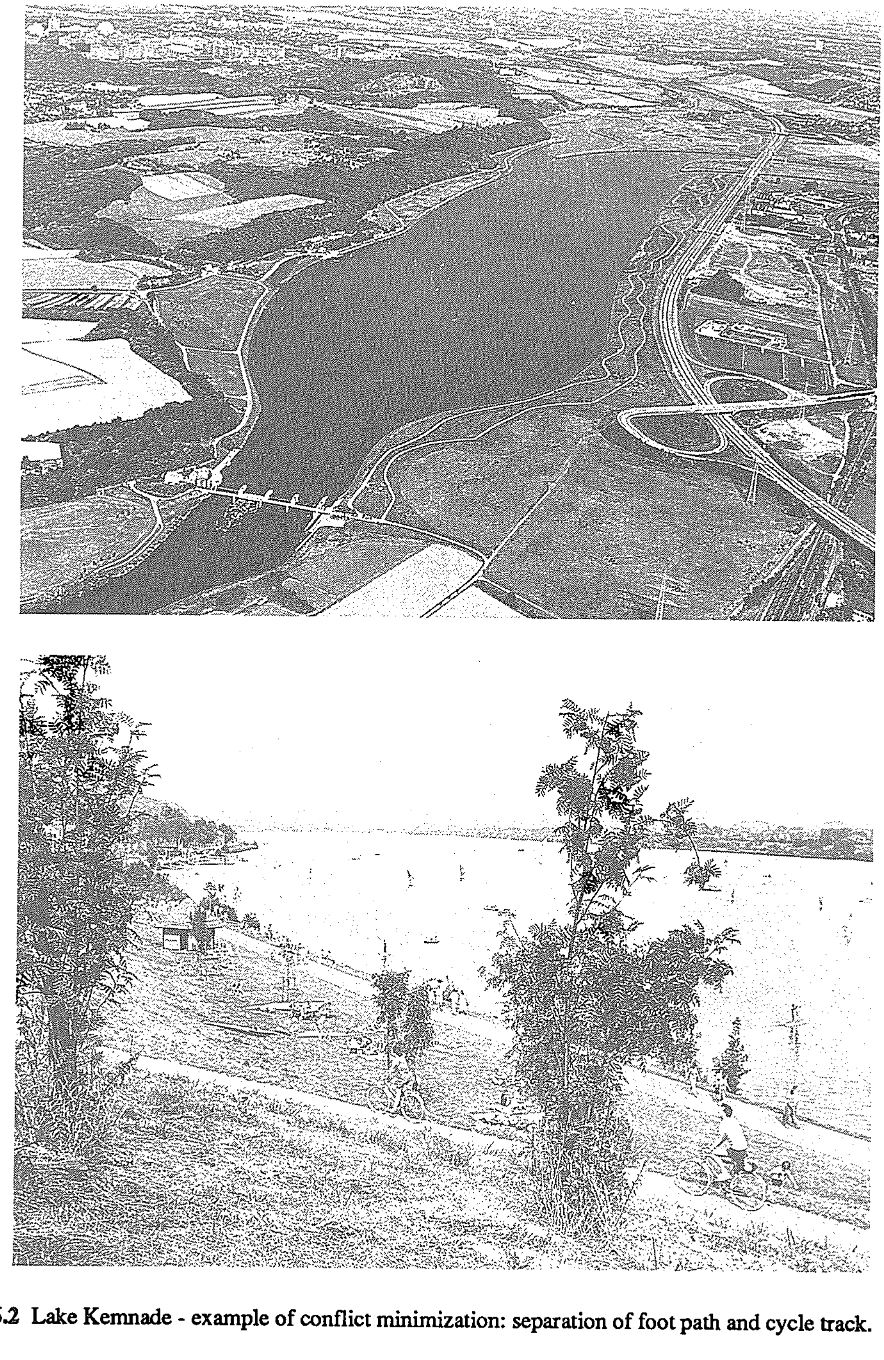
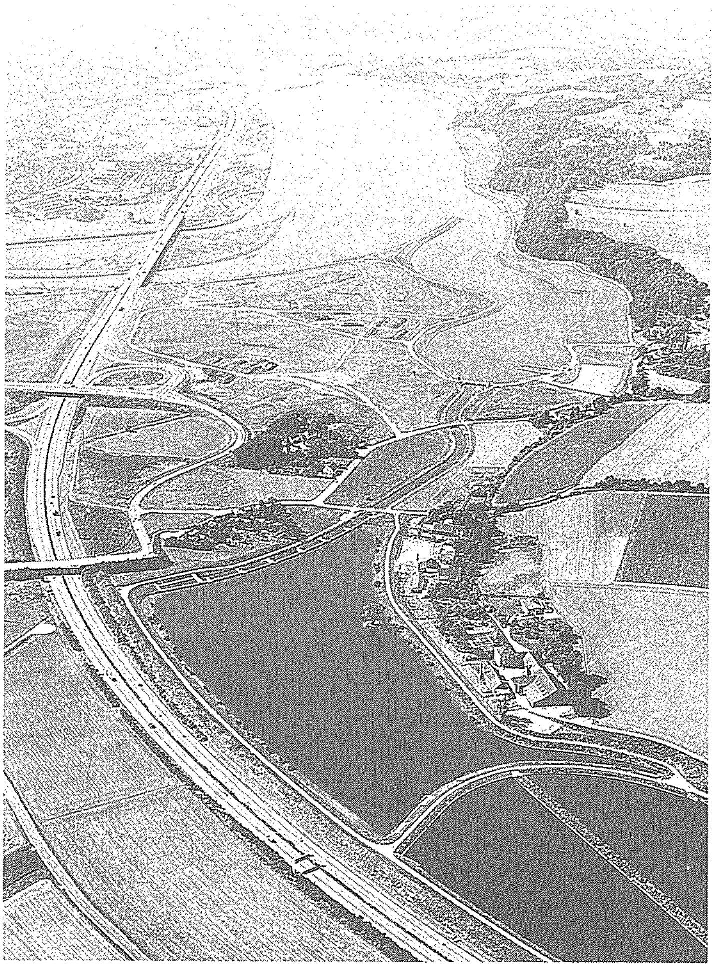


Pict. 6.1 Lake Kemnade, a Ruhr river impoundment for various recreational activities - example of compensatory measures: boat slide and fish ascensions steps at the weir.



Pict. 6.2 Lake Kemnade - example of conflict minimization: separation of foot path and cycle track.



Pict. 6.3 Lake Kemnade with harbour bay polishing lagoons

CHAPTER 7

SURVEY OF THE STATE OF WORLD LAKES

Tatuo Kira

7.1 ROLES OF LAKES

Freshwater is a requisite resource for human beings. In former days, rivers were the main source of water for residents of mountainous regions such as Japan, while people in plain regions used to depend on groundwater. If there was a lake with good water quality nearby, people on the lake shore, naturally enough, used water from the lake, but generally lakes were of greater importance for fisheries and water-borne transportation than for water supply. With population increase and urban development, however, larger water sources came to be needed for city water supply, and lakes became more and more important as sources capable of providing a large amount of water. Since river water flux tends to fluctuate widely and is less reliable, man-made lakes are created by damming rivers where appropriate lakes are not found, and are used as stable water sources for municipal use, irrigation, and hydroelectric power generation. Beside millions of natural lakes on the earth, the number of reservoirs of various sizes has been increasing very rapidly. Japan, for example, has some 100 natural lakes with areas wider than 1 km^2, while there are as many as nearly three times that number of reservoirs of the same size range.

Thus, lakes are now expected to serve not only for such traditional uses as fishery and transportation but also as important water sources. However, it should be noted that, unlike ever-flowing water in rivers, water in lakes remains stagnant for several months to decades, or in some lakes even longer than a hundred years, and therefore tends to be easily polluted. Lakes suffer from water quality degradation, if human activities are intensified and population increases around them. Consequently, much attention has to be paid to maintaining lake environments in sound conditions in order to coexist with lakes for sustainable use of their resources. To achieve that, not only the lake itself, but also the area gathering rainwater into it - referred to as the catchment area - should be managed in a rational way as an inseparable system.

7.2 SURVEY OF THE STATE OF WORLD LAKES BY ILEC/UNEP

The International Lake Environment Committee (ILEC) is a non-governmental organization located in Kusatsu with the aim of formulating and disseminating such environmentally sound management of lakes and reservoirs worldwide. Its core is the Scientific Committee that consists of 16 experts from 14 countries and a member of the United Nations Environment Programme (UNEP). Supporting the Committee's activity is one of the main tasks of the Foundation.

Immediately after its foundation in 1986, ILEC initiated, in cooperation with UNEP, a project called the "Survey of the State of World Lakes", which aimed at collecting and compiling environmental data on as many important lakes of the world as possible to be used as the basis for the management of lakes. Efforts have been made to collect not only natural scientific data on lakes themselves, but also environmental and socio-economic data on their catchment areas. This is the first attempt of its kind ever made. The Lake Biwa Research Institute has fully supported this survey by serving as the editorial body.

The results so far obtained from the survey have been published in five volumes of the "Data Book of World Lake Environments" (1988-1990). These volumes contain sets of detailed data on 217 lakes from all over the world: 64 from Asia, 4 from Oceania, 20 from Africa, 56 from Europe, 61 North America, and 12 from South America (Table 7.1). The lakes belong to 73 countries and 41 of them are man-made reservoirs, while the rest (176) are natural lakes.

Table 7.1 Number of lakes so far surveyed.

	Number of Countries	Natural	No. of lakes man-made	Total
Asia	15*	46	18	64
Oceania	2	3	1	4
Europe	25*	51	5	56
Africa	19	15	5	20
North America	5	54	7	61
South America	8	7	5	12
Total	73	176	41	217

*: Russia is included twice in both Asia and Europe.

Table 7.2 Size (surface area) distribution of surveyed lakes.

	Lake surface area (km^2)								
	<100	100-250	250-500	500-1000	1000-5000	5000-10000	10000-50000	50000-100000	Total
Asia	43	7	-	3	7	2	2	-	64
Oceania	2	-	-	1	-	1	-	-	4
Europe	34	4	6	4	4	3	1	-	56
Africa	5	-	2	-	4	6	2	1	20
North America	32	4	6	2	10	-	4	3	61
South America	5	1	1	3	1	1	-	-	12
Total	121	16	15	13	26	13	9	4	217

As shown in **Table 7.2**, small lakes, less than 100 km^2 in surface area account for about 50% of the survey, simply because smaller lakes can be more easily studied and hence are richer in available data. Although there are 253 "large lakes" (larger than 500 km^2 in the world) - Japan has only one, Lake Biwa - excluding man-made lakes, only 25% of these have been covered by this survey so far.

7.3 SIX MAJOR ENVIRONMENTAL PROBLEMS IN WORLD LAKES AND RESERVOIRS

The data collected by ILEC indicates that various environmental disruptions are now widespread among lakes and reservoirs in the greater part of the continents, leading to the crisis of water resources and aquatic ecosystems. There are some common features in the disruptions which may be classified into the following six categories.

1) Lowering of lake water level due to the over-use of water from lakes and/or inflowing/outflowing rivers, resulting in a decrease in lake water volume, the deterioration of water quality and changes in lake ecosystems.

2) Rapid siltation in lakes and reservoirs caused by accelerated soil erosion resulting from the overuse or misuse of arable, grazing and forest lands within their catchment basins.

3) Acidification of lake water due to prevailing acid precipitation, resulting in the extinction of fish and the degradation of ecosystems.

4) Contamination of lake water, sediments and organisms with toxic chemicals contained in agricultural chemicals and industrial wastes.

5) Eutrophication due to the inflow of such nutrients as nitrogen and phosphorus compounds in waste water discharged from industrial plants, agricultural lands, homes, urban and road surfaces, etc., resulting in heavy blooms of plankton, the deterioration of water quality, the decrease of bio-diversity.

6) In extreme cases, the complete collapse of aquatic ecosystems.

7.4 LOWERING OF LAKE WATER LEVEL

The worst example of lowering lake water level is the case of the Aral Sea (see Chapter 4) in the central Asian desert in Kazakhstan and Uzbekistan Republic, which has recently received much media attention. The Aral Sea was the fourth largest lake in the world, some 100 times as wide as Lake Biwa. The lake water was brackish with a salt concentration of one-fifth of sea water, and was fed by two tributaries originating from glaciers in the Pamir Highlands and the Tien-shan Mountains. Since the 1960s, an extensive agricultural development plan was initiated in the watersheds of these rivers by taking a large amount of river water for irrigation. As a result, the river flow failed to reach the lake, which then started shrinking.

During the past 30 years, the Aral Sea has lost one-third of its area and two-thirds of its water volume, salt concentration in lake water have reached four times the former level and almost all native organisms have disappeared. The shore line has retreated by several tens to 100 kilometers and ships in harbors are now left buried in desert sands. Fisheries in the lake have been completely destroyed. The pollution by agricultural chemicals and increased salt concentration in drinking water are now badly spoiling the lives of local people and their health. ILEC has been participating in an international experts meeting for preparing an action plan to cope with these problems, but it is by no means a simple task.

Symptoms caused by the subsidence of water level due to the abuse of lake water for power generation and irrigation are also known in other freshwater lakes. In many of those cases, it is noticeable that the deterioration of the water quality, especially eutrophication, took place. Future studies and more information are needed on this point.

7.5 ERODED SOIL FILLS LAKES AND RESERVOIRS

Soil erosion and resultant rapid siltation in lakes are one of the most serious disasters in developing countries. For instance, Lake Dongtinhu, the second largest freshwater lake in China, on the middle reaches of the Chiang-Jiang (Yangtze River), receives flood water from the river every summer and is now accumulating new sediments at a rate of 5-6 cm per year. This means that the lake with an average depth of 6-7 m, may fill up and disappear within a 100 years or so. This is a critical problem which may completely upset the way of life in the lakeside community.

It is said that the Chiang-Jiang has become more and more muddy in recent years as the result of increasing soil erosion in its upper reaches. In Yunnan Province, one of the headwaters of the river, the original vegetation was the evergreen forests of oaks, Castanopsis, tree of the camphor family, etc., just like those in the southwestern part of Japan, but they have been mostly turned into secondary forests of pine and bare lands which are now used as pastures. In order to increase food production to meet the ever-growing population, hill slopes are now extensively cultivated in addition to farmlands on narrow plains along valleys. Furthermore, people want to get more cash income, since even remote rural areas have been incorporated in the global market economy everywhere in the world. The main cash crop in Yunnan is tobacco and tobacco fields are now spreading over hill slopes further and further upwards. Reckless hill-slope cultivation has caused terrible soil erosion. Probably for the same reason, overgrazing is very often observed in pastures on slopes, where the trampling by livestock has broken continuous grass cover to result in the start of soil erosion, which may eventually lead to the collapse of whole slopes in some paces. Streams are always heavily loaded with mud even on fine days, flowing down continuously toward the Chiang-Jiang.

7.6 EUTROPHICATION

The eutrophication of Lake Biwa began around 1960, simultaneously with the start of the post-war economic growth of Japan. The deterioration of the lake's water quality has continued ever since, causing serious concern among 13 million people who depend on the Lake Biwa/Yodo River system for their water supply.

Observation of the changes in the plankton biomass at the center of Lake Biwa during the past 35 years indicates that the biomass in the 1980s is more than ten times as large as that in 1950. During the course of this rapid increase, clogging trouble in sand filters took place as early as in 1958 at the Municipal Water Purification Plant of Kyoto. Since 1969, unpleasant musty odors in the tap water of Lake Biwa origin became an annoyance for the users every summer. The plankton biomass peaked in the late 1970s, when the bloom of a flagellate plankton, *Urgolena americana*, appeared as "freshwater red tide". It has occurred almost every year since 1977, in spite of all the cooperative efforts made by the residents and local government of Shiga Prefecture. Though the trend of water quality degradation has more or less leveled off, signs of the bloom of such blue-green algae as *Microcystis* and *Anabaena* - an indicator of more advanced eutrophication - has appeared since 1983.

Fortunately, the eutrophication of Lake Biwa is not as serious as in some other lakes. For instance, Dianchi, a lake about half as wide as Lake Biwa located near Kunming City, the capital of Yunnan Province in China, is suffering from extreme eutrophication, because of the untreated wastewater it receives from the two million population of Kunming and a suburban industrial center consisting of some 160 factories. Up to the late 80s, nevertheless, many fish pens for breeding carp were floating on the lake surface. When I visited the lake again recently, however, its vast surface was covered by dense blooms of algae like green dye and fish-breeding was almost totally abandoned because of the lack of dissolved oxygen in lake water. Nearly all the native waterweeds and some 20 species of fish had been made extinct. Millions of pond snails that died of oxygen deficit in the bottom water were floating on the surface. The ecosystem of the lake had been completely destroyed. Ironically, city water supply for two million residents of Kunming are running short, and the city has begun to take this hypertrophic lake water as a source of tap water this year. The water authorities are now facing great difficulties in supplying tap water that meets the legal standards.

Such an example illustrates how important it is to prevent the advance of eutrophication beyond the stage of present-day Lake Biwa.

7.7 PRELIMINARY ANALYSIS OF THE DATA COLLECTED BY ILEC/UNEP SURVEY

Coming back to the topic of ILEC/UNEP project again, this survey is expected to continue for a few more years. Therefore, we have not yet undertaken comprehensive analyses of the data collected. Nevertheless, a preliminary analysis demonstrated some interesting relationships.

Transparency, is one of the most easily measurable indices of water quality and a sufficient number of observed values are available. It was found that the volume of lake water was most closely correlated with transparency as shown in Figure 7.1. In the figure, there is a difference of magnitude of ten million in lake volume, ranging from the world-largest Lake Baikal at the right end to very small lakes on the left end. Logarithmic scales were therefore used for both axes to incorporate such widely varying data into a graph. Although the points each corresponding to a lake are very scattered, you may see a broad positive correlation between transparency and lake volume as approximated by a dotted line in Figure 7.1. Some points far below the dotted line represent shallow, wind-swept lakes on plains such as Tai-hu (China), Lake Balaton (Hungary) and Lake Winnipeg (Canada), in which the water tends to be always turbid with suspended muds, whereas the points far above the line correspond to such lakes as Mashu-ko in Hokkaido and Lake Tahoe on the border between California and Nevada, well known for their very clear water.

This positive correlation may indicate that the larger the lake volume the more resistant is the lake to the decline of transparency caused by the inflow of silt and/or eutrophication. This suggests, in turn, the importance of lake water volume as a parameter in the analysis of the relationships between water quality and the conditions of catchment land area responsible for the pollution of lakes.

The degree of turbidity can be expressed by the concentration of suspended solids (SS) or the amount of particles suspended in water. As an example, Figure 7.2 shows the relationships between SS and the ratio of forest area to the whole catchment area. In the figure, closed circles represent Japanese lakes, in which a more or less inversely proportional relationship is recognised. The turbidity of lake water was found to increase significantly if the area ratio of forest came to less than 50%. However, contrary to our expectation, no clear relationship between the two variables was obtained when non-Japanese lakes shown by open circles were put together.

In the next step, parameters more closely related to SS were sought by dividing the characteristic values of catchment areas such as forest and farmland areas, population, etc., by lake water volume and converting them to specific values per unit lake volume. As illustrated in Figure 7.3, the area of farmlands - including both crop fields and pastures in this case - in the catchment area per unit volume of lake water (in terms of km^2 per million cubic meter or km^2/m^3) was the most influential factor for SS or turbidity. Thus from a global point of view, the progress of farmland development seems to be inevitably associated with the acceleration of soil erosion. It should be noted, however, that the relationship shown by a curve in Figure 7.3, is only valid for lakes under relatively moist climates with closed circles, while it is not for lakes in arid regions marked by open circles. Unfortunately, available data on SS values in lakes of arid regions were too limited to draw any conclusions.

Figure 7.4 shows the relationships between total nitrogen and total phosphorous concentrations in lake water, indicators of the degree of eutrophication, and the catchment area population per unit volume of lake water. Since the data are also plotted on logarithmic coordinates, the deviation of the value for each lake from the regression lines is much wider than its visual impression. Thus there are differences greater than two times in the concentrations of phosphorus and nitrogen corresponding to the same value of abscissa. Though individual lakes are no doubt influenced by specific conditions, we may assume that the population increase in the catchment area is the leading factor for accelerating eutrophication in world lakes. After the completion of this survey, more comprehensive and detailed analyses of the data are expected to identify the factors responsible for the deviation mentioned above.

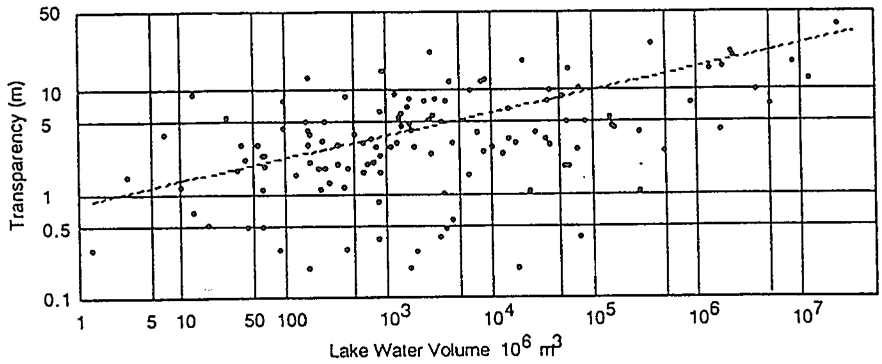


Fig. 7.1 Relationship between Transparency and Lake Water Volume

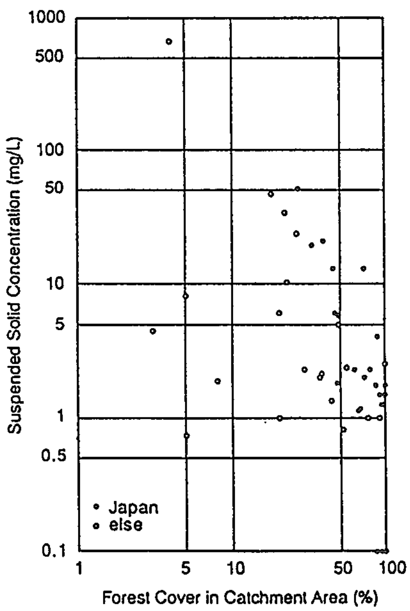


Fig. 7.2 Relationship between Suspended Solid Concentration and Percent Forest Cover in Catchment Area

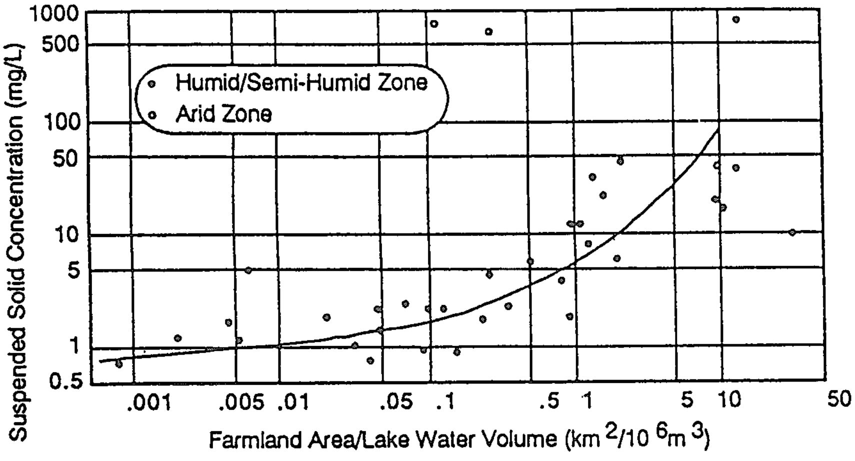


Fig. 7.3 Relationship between Suspended Solid Concentration and Farmland Area in Catchment Area

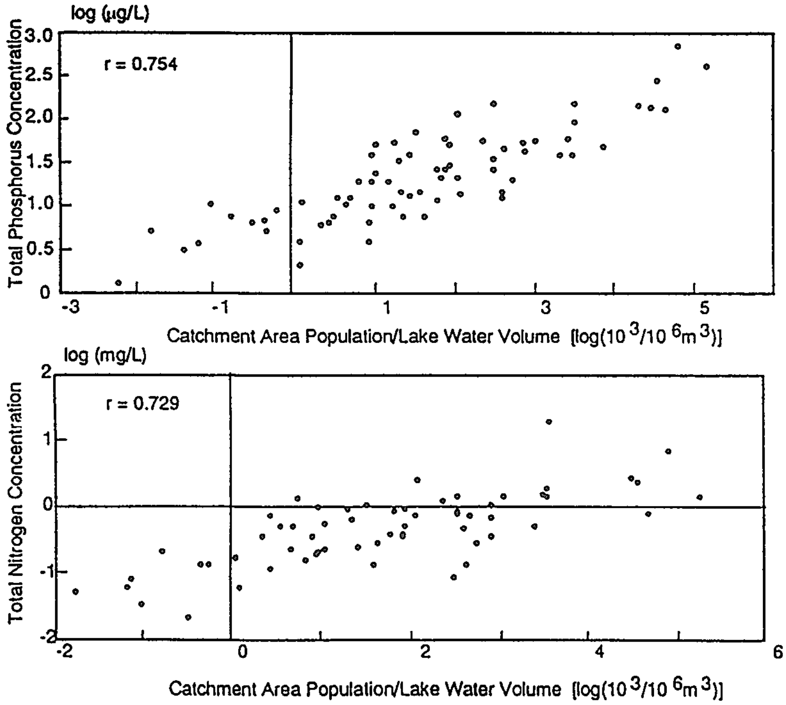


Fig. 7.4 Relationship between Total Phosphorus and Total Nitrogen concentration and Population in Catchment Area

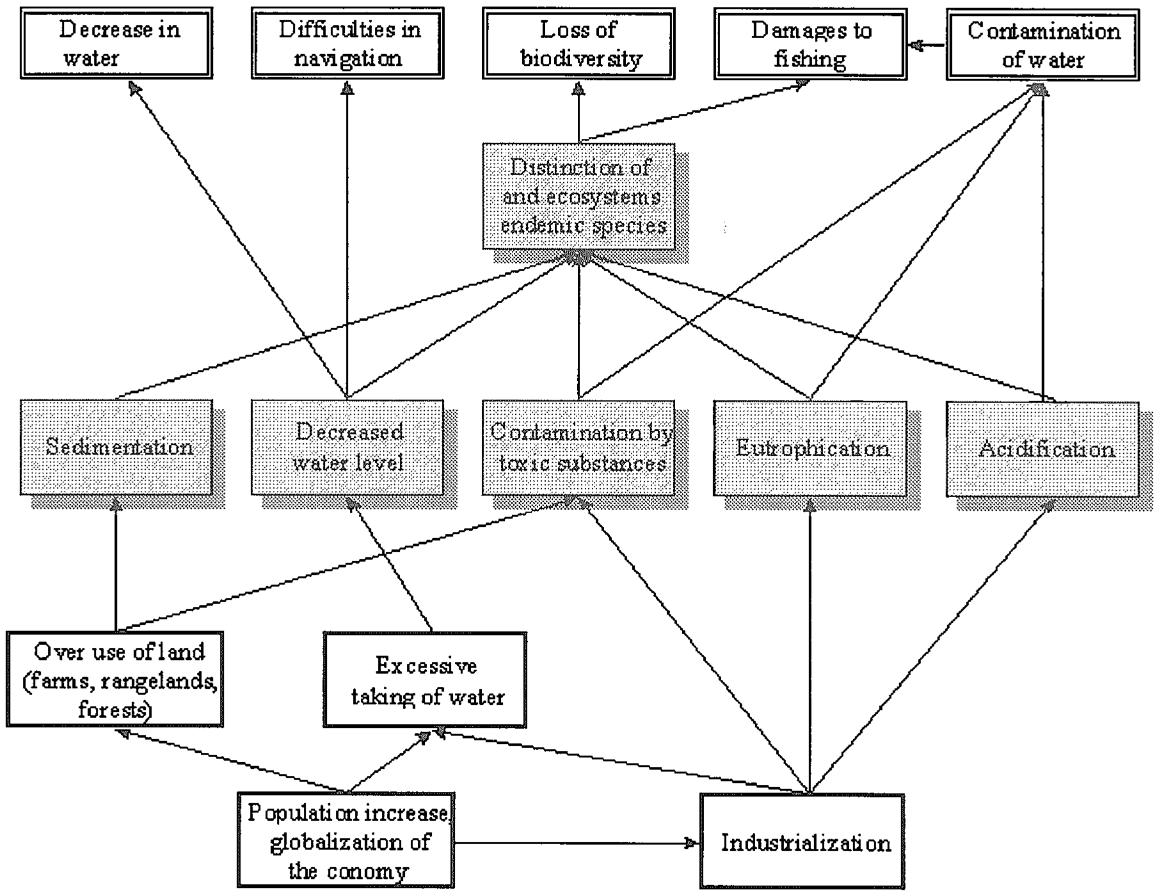


Fig. 7.5 Six major enviromental problems in world lakes and reservoirs.

CHAPTER 8

CONCLUSIONS

Sven Erik Jørgensen & Saburo Matsui

This chapter presents the conclusions of this guideline book on "The World's Lakes in Crisis" as a dialogue between Dr. Sven Erik Jørgensen, Chairperson of ILEC's Scientific Committee and Dr. Saburo Matsui, Secretary of ILEC's Scientific Committee to highlight important points of the problems that we are facing in lakes and reservoirs on a global scale.

8.1 SIX MAJOR PROBLEMS OF LAKES AND RESERVOIRS

Matsui: It may be helpful to the readers of this guideline book by starting the discussion on Chapter 7, Survey of the State of World Lakes. In the Chapter, Dr. Kira, the former Chairperson of ILEC's Scientific Committee has summarized six major environmental problems in world lakes and reservoirs, namely accelerated siltation, decline of water level, toxic contamination, eutrophication, acidification and extermination of ecosystems and biota. Dr. Jørgensen, how could this massive deterioration of the world's lakes and reservoirs take place during such a short period of time, only a few decades?

Jørgensen: During the last 40-50 years, the world's population has more than doubled and the total industrial and agricultural production is more than fourfold higher today than in the fifties. The total impact on nature is probably in the order of 8 times higher today than 40-50 years ago, if we consider the growth in population, in industrial and agricultural production and the technological development (we use more chemicals, the traffic has increased enormously and so on). We *have* realized that we cannot continue in that manner, and therefore we have started over the last 10-20 years in several industrialized countries to take initiatives to reduce this impact on nature, but we are still doing far too little compared with the magnitude of the problem. Furthermore, it will take some time before all countries will do what they can to reduce the pollution, but it is extremely important that the developing countries are not making the same mistakes as we did in the industrialized countries and learn from our mistakes. It is also important that the industrialized countries support the developing countries in their effort to abate pollution. We have already the knowledge regarding how to solve the problems, it is therefore very much a question of political will. Let me propose to discuss each of the six problems that Dr. Kira has mentioned in his Chapter to stress that we do know about the problems and about how to solve and prevent them.

Matsui: Yes, I agree that the six problems have the same basic cause, namely that the development has been out of control. The six problems are, however, quite different with relation to where we have failed in our management control and what we have to do to solve the problems.

Could you explain what accelerated siltation is and what has caused it?

8.2 SILTATION AND DECLINE OF WATER LEVEL

Jørgensen: The cause of accelerated siltation can be attributed to soil erosion resulting from over-use or misuse of arable, grazing and forest lands within the catchment areas. Mining activity becomes also a source of silt to water courses. Rapid siltation causes many problems including rising bed levels, and reduction of littoral zones, wetlands and meadows, etc.. Physical and geological changes in lakes and reservoirs have fundamentally influenced the aquatic ecosystems as well as on the adjacent terrestrial ecosystems. Typical siltation problems are discussed in Chapter 3 "Endangered Chinese Lakes" by Drs. Yan & Zhang, where Lake Dongtinhu and Lake Poyanghu suffer from severe siltation problems. Both lakes are situated in the catchment of the middle reaches of the Changjian River (Long River), where a vicious circle of siltation-flood-reclamation was observed.

Wetlands are often the most vulnerable zones around lakes and reservoirs, where the pressure of reclamation is particularly high due to the growing demand for agricultural and industrial areas as well as for habitation zones. Wetlands are ecologically rich and complex including waterfowl that maintain migration and breeding as their life style. They are, furthermore, important buffer zones for lakes and reservoirs, as they are able to absorb a significant part of the impacts on these ecosystems. I can here refer to ILEC and UNEP's Guideline book Volume 3 on Lake Shore Management.

Matsui: The decline of water level has a similar influence on lakes and reservoirs. Do you see similar or different problems with the decline of water levels?

Jørgensen: The decline of water level is caused basically by over-exploitation of water from lakes and/or in flowing rivers, resulting in a decrease in water volume. Both siltation and decline of water level cause a decrease in water volume, which brings about loss of economic activities as well as deterioration of ecological systems in and/or around lakes and reservoirs. We have to have a broader scope of influences of siltation and water level decline on the lake and reservoir environment. A typical example of water level decline is the case of the Aral sea which was discussed in Chapter 4, by Dr. G.N. Golubev. Wetland protection is one of the global tasks stressed in the Ramsar Convention.

The solution to these problems are clear from Chapters 3 and 4. We need much better planning and conservation of our use of land and water. Conservation of wetlands is of particular importance for a proper solution of these problems.

Matsui: Let me also mention in this context the two Chapters by Drs Entz and Nusch. They show clearly the complexity of the problem and the relationship between the quality and quantity of water. What do you see as the main message in these two important papers?

Jørgensen: Both papers show in my opinion that a good management strategy included environmental impact assessment, EIA is absolutely necessary *before* you enter a major project. It will be much more costly to solve the problems of the unexpected adverse effects after the project has been realized.

8.3 TOXIC CHEMICAL CONTAMINATION PROBLEMS

Matsui: What do you see as the solution of toxic contamination in lakes and reservoirs?

Jørgensen: We should have a view of toxic chemicals in the manner of life cycle assessment. We may divide the chemicals into two groups: the group of chemicals of natural origin, including heavy metals, and the second group of man-made chemicals including trihalomethanes that are produced during chlorination of drinking water, and dioxins that are produced during combustion of chemicals and municipal solid wastes. The first group should be controlled at the source such as control at mining and smelting activities of heavy metals and control of smoke and water emitted from industries. If source control is difficult, controlled disposal and prevention of contamination become the only alternative solution. Dilution and dispersion of contaminants is not acceptable, as this method has faced many failures in the past. Heavy metals and other toxic elements should, to a higher extent, be recycled and a safe disposal approach should complete their life cycles. Modern society is shifting toward a recycle society that assesses a chemical in terms of benefit and cost, energy consumption, environmental contamination, etc.. Green taxes will enhance recycling and should be considered applied to a much higher extent in the coming years to modify the pattern of application.

The new man made chemicals should be assessed properly before being introduced into market consumption. We can see those assessment activities becoming obligatory in developed countries. However, we also know those activities have just been introduced during the last decade. We have not completed the assessment of the large number of synthetic chemicals that were already introduced on the global market. More than 100,000 chemicals are used in such an amount that they may threaten the environment.

Matsui: It means that monitoring of toxic chemicals in lakes and reservoirs is essential, but still weak in its activities. When we monitor contamination, we look only at the water phase. We often ignore other phases of the environment, which are sediments and organisms. We also often ignore migration of chemicals from air and to water which is pertinent for many agricultural chemicals. Sources of toxic chemicals are industrial waste water, domestic waste water, leachate from solid waste disposal sites as well as agricultural run off. Automobile exhaust gas contains also many toxic chemicals including poly-aromatic-hydrocarbons (PAHs), many of them being potential mutagen and carcinogen. The storm water run-off from roads flush out those chemicals to aquatic ecosystems. Air pollution shifts thereby finally to water pollution problems.

Jørgensen: The developing countries where agricultural activities are the major economic drive, are confronted with a heavy contamination of insecticides and herbicides. The most under-developed countries may not face similar problems, because they are so poor that they cannot afford to purchase expensive pesticides.

Our approach to toxic chemicals has three basic ways for the developed countries. The one is reduction of toxic chemical uses, the second is to enhance recycling of heavy metals as much as possible, the third is strengthening science and technology for control of toxic chemicals in the environment including improvement of toxicity assessment, wide application of environmental risk assessment, new technology of detoxification of chemicals at sources and use of cleaner technology including substituting the most harmful chemicals to compounds with lower toxicity or harm to the environment.

8.4 EUTROPHICATION PROBLEMS

Matsui: Eutrophication problems are found in many lakes and reservoirs in both developed and developing countries. What do you see as the main reason for eutrophication?

Jørgensen: The most basic causes are derived from the drastic increase in food production due to human population growth. Chemical fertilizers of nitrogen and phosphate became relatively cheap so that massive use of those fertilizers made it possible to increase drastic food production by the so-called Green Revolution. However, run-off of those chemicals into lakes and reservoirs as well as coastal seas became triggers of eutrophication problems. Developed countries first faced the problems during the 1960s and early 70s.

Matsui: Most developed countries are still facing the problems and have introduced biological denitrification technology for treatment of municipal and industrial waste water. Phosphate removal is also available for municipal waste water treatment either as a chemical or biological process. Denitrification is the conversion of dissolved nitrogen into dinitrogen gas. This biological process requires a carbon source to drive the denitrification process. There is a limitation of the process in terms of carbon availability at low price. When carbon sources are not sufficient, which happen in most of municipal waste water treatment plants, nitrous oxide gas is formed instead of nitrogen gas due to incomplete denitrification. Nitrous oxide gas is one of the many green house gases, although its contribution is not on the same high level as carbon dioxide. There is room here for environmental engineers to improve the denitrification process.

Jørgensen: Phosphorus is a basic element for biological activity on the earth. The natural sources of this element is very limiting. I can see more important aspects of phosphorus in terms of source scarcity in the 21st century. We need therefore to put more efforts on recovery of phosphate from waste water treatment plants. Thereby we could solve the problems of food production and eutrophication simultaneously.

Matsui: The current technology of recovery of phosphate from municipal waste water can meet such demand. The most advanced technology is a chemical process that can precipitate magnesium-ammonia-phosphate crystals. Developed countries should introduce such available technology in the near future.

Jørgensen: Compared to control of nitrogen and phosphate from point sources, which is indeed feasible today, non-point source control is very difficult. Some measures have been taken in Europe and the U.S. to control the nitrogen and phosphate pollution originated from the use of manure. It is also discussed to implement new regulations of uses of nitrogen and phosphate in agriculture. Recovery of phosphate and denitrification of agricultural run-off may be very difficult so that it is very necessary to force farmers to use less fertilizers. A wider use of wetlands as a pattern in the landscape could enhance the over-all capacity of denitrification in agricultural areas and can be strongly recommended as a possible tool in lake management. The European Union (EU) has, a few years ago, decided to take 10% of the arable land out of production. It would be beneficial for a solution of the eutrophication problem in the European aquatic ecosystems to use a significant amount of this fallowed land as artificial wetlands forming a pattern in the landscape.

Matsui: Eutrophication issues in developing countries are more difficult compared to developed countries. Chinese lakes face complicated problems of eutrophication, combined with other problems such as siltation and toxic contamination. Chapter 3 describes such examples by Drs. Yan and Zhang in which we can see eutrophication started earlier than 1960s, because of the old history of Chinese civilization. China developed aqua culture technology more than 2000 years ago to be able to supply a large population with fish as a major protein source. Eutrophication was a necessary side effect to aqua culture to a certain extent. However, China is now facing the problems of a hyper-eutrophication that has not been experienced in the industrialized countries.

Jørgensen: I know this hyper-eutrophication from Lake Taihu between Nanjing and Shanghai. More than 2 million people are dependent on Lake Taihu as their source of drinking water. At the same time, discharge of only primary treated waste water from the same population of more than 2 millions takes place. Removal of phosphate from the waste water and re-use of this phosphate in agriculture seem to be the first necessary steps to be taken to solve the hyper-eutrophication problem of Lake Taihu. In addition, it is also necessary to control the non-point pollution. The problem of hyper-eutrophication can only be solved by application of 1) better planning, 2) advanced waste water treatment, 3) control of non-point sources, 4) reduced use of fertilizers in agriculture and 5) creation of a pattern of wetlands in the landscape. All these measures have to be used *simultaneously*, and that is of course going to be expensive, but absolutely necessary.

8.5 ACIDIFICATION PROBLEMS

Matsui: It is also going to be expensive to solve the problem of lake acidification which is mentioned in Chapter 2 written by you. Do you, Dr. Jørgensen, see any improvements in Europe or North America, where this problem is most pronounced?

Jørgensen: Europe and North America have invested massively in high technological solutions for removal of sulphur dioxide and nitrogen oxides as air pollutants in emissions originated from combustion of fossil fuel. Further investment, mainly in the former communist countries in East and Central Europe, is still needed. It will still be another decade or two before the problem is solved properly, including the "death" of the coniferous forest in Central Europe, which is also associated with the acid precipitation.

Matsui: Acidification is associated with several indirect effects, such as enhanced release of heavy metals from sediment and impoverishment of the ecosystem due to decreased biodiversity. It will therefore require many years before these adverse effects of acidification have been eliminated.

Jørgensen: I fully agree. This demonstrates clearly that all the environmental problems should rather have been solved by prevention. It is far cheaper and more effective to use good planning and management at an early stage. This is an important lesson for the developing countries to learn. They should really not make the same mistakes as the industrialized countries, which started to discover the environmental problems and take them seriously too late.

Matsui: In the long run we have to solve the acidification problem by development of alternative energy sources such as wind and tide, and use of solar cells and maybe by fusion energy. Only by use of alternative energy sources can we come up with a real sustainable solution to these problems and the crucial global problem of the green house effect.

8.6 GLOBAL WARMING ISSUES FOR LAKES AND RESERVOIRS

Matsui: The global warming issues with relation to lakes and reservoirs are very important to those who are concerned with environmental works. The paper written by Dr. James P. Bruce is one of the earliest papers dealing with the consequences of global warming for lakes and reservoirs. He writes about several adverse effects of the green house effect on the hydrology and water quality of lakes and reservoirs. He indicates in Chapter 1 several measures which could be taken, to reduce these adverse effects.

Jørgensen: There is no doubt that we must be prepared to meet the changes in water levels, which will be a consequence of the global warming due to a higher evapotranspiration. We can reduce these adverse effects by good management, but the root of the problem is our energy consumption. We need to reduce our energy consumption, save energy and find new alternative energy sources. This will probably require enormous investments to shift to other energy sources, but there is no other solution in the long run.

Matsui: With the falling water level, a wide spectrum of indirect effects will emerge. Higher temperature and less water in a lake will mean that the total amount of oxygen in the lake will be reduced significantly, less volume means less fish, higher temperature means less effective irrigation and so on. The biodiversity will also be reduced. Could you tell me, what do we know about the role of biodiversity for lake ecosystems?

Jørgensen: The role of biodiversity for ecosystem stability was very much discussed in the scientific literature in the seventies, and the conclusion was that there is no direct simple relationship between ecosystem stability and biodiversity. We can for instance see that a very eutrophic lake with a low biodiversity is very stable in a sense, that it is very difficult to get the lake back to a mesotrophic or oligotrophic state. Biodiversity is, however, extremely important for the ability of an ecosystem to meet new unexpected impacts. We may say that the higher the biodiversity, the higher is the probability that there are some species present that could maintain the function of the ecosystem in new and unexpected stress situations. Our general knowledge about the role of biodiversity for lakes and reservoirs is, however, very limited. More research in this field is urgently needed.

Matsui: The effects on lakes of global warming show the complexity of the problem, as clearly illustrated in Dr. Bruce's paper. The environmental management of the global warming issue will be extremely complicated and difficult to solve. How can we solve all these environmental problems simultaneously? It will be very expensive.

Jørgensen: Yes, there is no other way than to improve currently our management of lakes and reservoirs and to invest more and more money in a better environment for future generations. We are aware of the environmental problems and we have the know how, solution methods and the management strategies ready to solve these problems. Now, we need to take initiatives, many initiatives, in the right direction.

Matsui: The sooner we take the initiatives, the more manageable will the problems be. Environmental work in the developing countries is therefore a crucial component in a global environmental strategy. Let me in this context refer to Chapter 18 of Agenda 21 from the Rio Conference 1992, which must be understood fully in order to implement any measures for the development and protection of lakes and reservoirs. That is not to say that Chapter 18, is in itself the final answer. The recent report of the Sixth Session of the Commission on Sustainable Development (CSD), held in New York between 20 April - 1 May 1998, has a section on "Strategic Approaches to Freshwater Management", which deals in greater depth with the problems highlighted by Chapter 18. The unofficial text of the relevant part of the report is given as an Appendix in this book and should be studied as the latest guideline (at the time of going to press) from the United Nations for freshwater management.

APPENDIX*

Decisions of the Commission on Sustainable Development
Decision 6/1
Strategic Approaches to Freshwater Management

1. The Commission on Sustainable Development, having considered the reports of the Secretary-General on Strategic Approaches to Freshwater Management (E/CN.17/1998/2) and on the Activities of the United Nations System in the Field of Freshwater Resources (E/CN.17/1998/3), welcomes the report of the Ad-Hoc Intersessional Working Group of the Commission on Strategic Approaches to Freshwater Management (E/CN.17/1998/13), the Harare Expert Group Meeting on Strategic Approaches to Freshwater Management (E/CN.17/1998/2.add1 and E/CN.17/1998/11), and takes note of the outcome of the 1st Petersberg Round Table on Global Water Politics convened by the Government of Germany (E/CN.17/1998/17) and the Paris International Conference on Water and Sustainable Development convened by the Government of France (E/CN.17/1998/16).

2. The objectives of sustainable development and the links among its three components economic and social development and environmental protection were clearly articulated in Agenda 21 and the Rio Declaration. The specific decisions and policy recommendations concerning the application of integrated approaches to the development, management, use and protection of freshwater resources as elaborated in chapter 18 of Agenda 21 and the seven key areas contained in that chapter continue to be a fundamental basis for action and shall be implemented in accordance with the specific characteristics of each country.

3. In this regard, the Commission reaffirms that water resources are essential for satisfying basic human needs, health and food production, energy, the restoration and maintenance of ecosystems, and for social and economic development in general. Agriculture accounts for a major part of global freshwater use. It is imperative that freshwater resources development, use, management and protection should be planned in an integrated manner, taking into account both short- and long-term needs. Consequently, the priority to be accorded to the social dimension of freshwater management is of fundamental importance. This should be reflected in an integrated approach to freshwater in order to be coherent, aimed at achieving truly people-centered sustainable development in accordance with their local conditions. It is important that consideration

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*The information in this Appendix was taken directly from the UNOFFICIAL TEXT of the OUTCOME OF THE SIXTH SESSION OF THE COMMISSION ON SUSTAINABLE DEVELOPMENT held in NEW YORK 20 April - 1 May 1998 and posted on the Internet by the United Nations Department of Economic and Social Affairs (DESA).

of equitable and responsible use of water become an integral part in the formulation of strategic approaches to integrated water management at all levels, in particular in addressing the problems of people living in poverty. The development, management, protection and use of water so as to contribute to the eradication of poverty and the promotion of food security is an exceptionally important goal. The role of groundwater; rivers, lakes, streams and wetlands; estuaries and the sea; and forests, other vegetation, and other parts of their ecosystems in the water cycle and their importance to water quality and quantity should be acknowledged and protected. Another set of crucial issues relate to the links between water quality, sanitation and protection of human health.

4. Since 1992, marked improvements in water quality have occurred in a number of river basins and groundwater aquifers where pressures for action have been strong. However, overall progress has been neither sufficient nor comprehensive enough to reduce general trends of increasing water shortages, deteriorating water quality and growing stress on freshwater ecosystems and on the natural hydrological cycle. Water must not become a limiting factor for sustainable development and human welfare. A series of potential water related problems can be averted if appropriate action is taken now towards and integrated approach to an efficient use, development, management, protection and use of freshwater resources.

5. Competition for limited freshwater increasingly occurs between agricultural, rural, urban, industrial and environmental uses. In adopting the Programme for the Further Implementation of Agenda 21, in particular its paragraph 34, the General Assembly, recognized the importance of taking into account, while dealing with freshwater development and management, the differing level of socio-economic development prevalent in developing countries. The General Assembly recognized, inter alia, the urgent need to formulate and implement national policies of integrated watershed management in a fully participatory manner aimed at achieving and integrating economic, social and environmental objectives of sustainable development. In addition to agreeing to those strategic principles, the General Assembly also recognized an urgent need to strengthen international cooperation to support local, national and regional action, in particular in the fields of environment and development, safe water supply and sanitation, food security and agricultural production, energy, flood and drought management, recycling through efforts in areas such as information exchange, capacity-building, technology transfer and financing.

6. The process called for in the Programme for the Further Implementation of Agenda 21 should focus on fostering and supporting national, regional and international action in those areas where goals and objectives have been defined; on the identification of existing gaps and emerging issues; on the development of education and learning systems and also on building global consensus where further understanding is required; and promoting greater coordination in approaches by the United Nations and relevant international institutions, particularly in support of national implementation policy and development.

7. The implementation of integrated water resources development, management, protection and use require action at all levels with the technical and financial support of the international community. Those actions should be closely related to other areas of natural resource management, including biodiversity, coastal zone, agriculture, land, forestry and mountain development. Effective integrated water resource management should incorporate approaches dealing with river basins, watershed management and ecosystem maintenance, where decision making needs to be supported by education.

8. There is need to put in place local and national management plans to bring about productive and sustainable interactions between human activities and the ecological functioning of freshwater systems based on the natural hydrological cycle with the technical and financial support of the international community. Such plans need to minimize the adverse impacts of human activities on wetlands and coastal areas, estuarine and marine environments, and in mountainous areas, and to reduce potential losses from droughts and floods, erosion, desertification and natural disasters. Furthermore, sanitation, pollution prevention, proliferation of aquatic weeds, especially water hyacinth, and the treatment and recycling of waste water need to be addressed.

9. Local integrated water management plans require detailed assessment of water resources requirements including the exact nature of the demands and an estimate of the catchment yield. In this regard, there is a need to reduce and eliminate unsustainable patterns of production and consumption, and to promote appropriate demographic policies.

The Commission, therefore:

10. Urges Governments, with the technical and financial support of the international community, where appropriate, to address the numerous gaps identified in the path towards integrated water resources development management, protection and use. Areas that require further attention include: meeting basic health education needs and raising awareness of the scope and function of surface and groundwater resources; the need for human resource development and participatory approaches, notably including women and local communities and integrating freshwater issues into local Agenda 21 processes; the role of ecosystems in the provision of goods and services; balancing structural and non-structural approaches; explicit linkages with socio-economic development, for equitable utilization and efficient freshwater allocation and use; improved sanitation and waste-water treatment and recycling; conserving the biological diversity of freshwater ecosystems; conservation and sustainable use of wetlands; the understanding of hydrology and the capacity to assess the availability and variability of water resources; and through mobilization of financial resources, and the mainstreaming of gender issues into all aspects of water resources management; and wasteful water usage. Strategic and integrated actions are still needed in order to adapt to ever changing social and environmental circumstances and to address fundamental concerns for combatting poverty, ensuring adequate provision of public health, food security and energy, and better to protect the environment. International cooperation and action needs to address

effectively the above issues, building on existing consensus for the successful implementation of integrated water resource development, management, protection and use.

11. Encourages riparian States to cooperate on matters related to international watercourses, whether transboundary or boundary, taking into account appropriate arrangements and/or mechanisms and the interests of all riparian States concerned, relevant to effective development, management, protection and use of water resources.

12. Encourages riparian states on the basis of mutual agreement and common interest of all riparian states concerned, to establish, where appropriate, organisations at the river basin level for the implementation of water management programmes. Within its existing guidelines, the Global Environmental Facility (GEF) is invited to consider supporting such developments as part of its international water portfolio. All these actions should be complemented by activities to support effective national water policies and strategies in the developing countries affected by desertification and drought, particularly those in Africa.

13. Encourages Governments, at the appropriate level, in accordance with the specific characteristics of each country, to formulate and publish the main goals, long and short term objectives and general principles of water policies and implement them by means of comprehensive programmes. The implementation of local or national programmes should form an important part of the local Agenda 21 approach.

14. Encourages governments, at the appropriate level, while formulating integrated water resources management policies and programmes to implement relevant conventions in force. In particular, the relevant conventions on biological diversity, desertification, climate change, and wetlands and the Convention on International Trade in Endangered Species of Flora and Fauna (CITES) need to be considered. In addition, consideration should be given, as appropriate, to relevant recommendations and/or programmes of action emanating from a number of major international conferences and events. Furthermore, in formulating such policies, the Commission invites Governments to address the need for achieving universal access to water supply and sanitation, with poverty eradication being one of the objectives, taking into account, in particular, chapter 18 of Agenda 21 and relevant recommendations of conferences and events.

15. Recognizes that the Expert Meetings as well as international conferences provided useful information and valuable inputs for intergovernmental deliberations and negotiations at the 6th session of the CSD. It is important that more such meetings be held in developing countries. Invites Governments to consider, as appropriate, the key recommendations stemming from the report of the Harare Expert Group Meeting on Strategic Approaches to Freshwater Management and the outcome of the Paris International Conference on Water and Sustainable Development.

A. Information and data for decision-making

16. Information and data are key elements for assisting the management and use of water resources and in the protection of the environment. All states, according to their capacity and available resources, are encouraged to collect, store, process and analyse water related data in a transparent manner and make such data and forecasts publicly available in the framework of a participatory approach. Because women have a particular role in utilising and conserving water resources on a daily basis, their knowledge and experience should be considered as a component of any sustainable water management programme.

The Commission therefore:

17. Encourages Governments to establish and maintain effective information and monitoring networks and further promote the exchange and dissemination of information relevant for policy formulation, planning, investment and operational decisions, including data collected based on gender differences, where appropriate, regarding both surface and groundwater, and quantity, quality and uses as well as related ecosystems and to harmonise data collection at the local catchment and the basin/aquifer level. Information concerning all relevant factors affecting demand is also essential.

18. Stresses that effective management of water resources demands that attention should be paid to essential activities, all of which require fundamental knowledge about water resources as well as information about water quality, quantity and uses, including: (a) water resources planning and watershed management at local and national levels; (b) regulatory activities; (c) investments in infrastructure and technologies for remedying and preventing pollution; and (d) education and training.

19. Encourages Governments to facilitate the collection and dissemination of water data and documentation that enhances public awareness of important water-related issues, to improve the understanding of meteorology and processes related to water quantity and quality and the functioning of ecosystems, and to strengthen relevant information systems for forecasting and managing uncertainty regarding water resources. Such efforts on the part of developing countries, particularly the least developed countries, require support from the international community.

20. Governments are encouraged to design programmes aimed at increasing public awareness on the need to conserve, protect and use water sustainably and allow local communities to participate in monitoring of water related indicators. This information should then be made available for community participation in decision making.

21. Also encourages Governments, taking into account their financial and human resources, to develop and implement national and local water related indicators of progress in achieving integrated water resource management, including water quality and quantity objectives, taking into account ongoing work of the Commission on Sustainable

Development on indicators of sustainable development. In addition, in accordance with their policies, priorities and resources, Governments may find it useful to carry out national water quality and quantity inventories for surface water and groundwater, including the identification of gaps in available information.

22. Invites Governments to establish or strengthen mechanisms for consultations on drought and flood preparedness and early warning systems and mitigation plans at all appropriate levels. They are encouraged to consider the establishment of rapid intervention systems to ensure that individuals and communities can be assisted in recovering from damage that they suffer from such extreme events. At the international level, there is, in particular, need to maintain support of these activities at the conclusion of the International Decade on Natural Disaster Reduction.

23. Calls upon the international community, including the United Nations system, to support national efforts in information and data collection and dissemination through coordinated and differentiated action. In particular in their respective fields, United Nations agencies and programmes and other international bodies should support Governments in the development and coordination of relevant data and information networks at the appropriate level, carry out periodic global assessments and analyses of water resources availability (both quality and quantity) and changes in demand, to assist in identifying water related problems and environmental issues, and promote the broadest exchange and dissemination of relevant information, in particular to developing countries. Encourage access to, and exchange of, information in user friendly formats based on terminology easily understood.

B. Institutions, capacity-building and participation

The Commission on Sustainable Development

24. Urges Governments to establish national coordination mechanisms across all sectors, as already envisaged in the Mar del Plata Action Plan, providing for contributions from government, public authorities, and the participation of civil society, including communities affected, in the formulation and implementation of integrated water resource development and management plans and policies. Such mechanisms should also provide for participation by communities and water users. This involves the participation, at the appropriate levels, of water users and the public in planning, implementing, and evaluating water resources activities. It is particularly important to broaden women's participation and integrate gender analysis in water planning.

25. Invites Governments to take the necessary steps to establish legislative and regulatory frameworks and to improve such frameworks where they exist to facilitate integrated water resource management and strategies, including both demand and supply management as well as the links with the management of land use, taking into account the need to build capacity to apply and enforce such frameworks. Each Government

needs to define its relevant functions and distinguish between those related to standards, regulation-setting and control, on the one hand, and the direct management and provision of services, on the other.

26. Encourages Governments to consider how best to devolve responsibilities to the lowest appropriate level for the organization and management of public water supply, sanitation services and irrigation systems, as well as water resources management within the framework of national water policies.

27. Urges Governments to strengthen institutional and human capacities at the national, sub-national and local levels, in view of the complexity of implementing integrated water resource development and management strategies particularly in large urban settlements. This could be done through local Agenda 21 processes, where they exist. Effective water resource development, management and protection requires appropriate tools for educating and training water management staff and water users at all levels and for ensuring that women, youth, indigenous people, and local communities have equal access to education and training programmes. Design of these programmes should be done in cooperation with stakeholders.

28. Encourages Governments to establish an enabling environment to facilitate partnerships between public and private sectors and non-governmental organizations, aiming towards improved local capacity to protect water resources, through educational programmes and public access to information. At the global level, appropriate existing mechanisms can provide a universal forum for debate and the development of thinking. The pivotal role of women should be reflected in institutional arrangements for the development, management, protection and use of water resources. There is a need to strengthen the role of women, who should have an equal voice with regard to water resource development, management, protection and use and in the sharing of benefits.

29. Encourages public authorities, public and private companies and NGOs dealing with the formulation, arrangement and financing of water resources programmes to engage in a dialogue with users. This dialogue requires the sharing of information with interested parties regarding the sustainable use of water and relationships with land use, public access to information and data, and discussions on objectives and implementation modalities, in accordance with the national legislation of each country.

30. Calls upon the international community, in particular, the organizations of the United Nations system, especially the United Nations Development Programme, to strengthen capacity-building programmes, taking into account the special needs of developing countries, in particular the least developed countries and the specific circumstances of small island developing States, in areas such as training, institutional development and the participation of women, youth, indigenous people, and local communities in support of national efforts in this field.

C. Technology transfer and research cooperation

The Commission on Sustainable Development:

31. Encourages Governments to remove impediments to and stimulate research and development cooperation, together with the development of technologies for sustainable water management and use, and to increase efficiency, reduce pollution and proliferation of aquatic weeds, especially water hyacinths and promote sustainable agriculture and food production systems. This also applies in the areas of desalination, brackish water treatment, waste water treatment, management of wetlands, drainage water reuse, improving chemical quality of ground water, including treatment of arsenic and other harmful heavy metals, and desert dew catchment, and in the use of remote sensing techniques and other relevant modern technologies in order to help increase the supplies of freshwater. All this involves the adaptation and diffusion of new and innovative techniques and technologies, both private and public, and the transfer of technologies to developing countries. In this context, the Commission urges developed countries to strengthen research cooperation and to promote, facilitate, and finance, as appropriate, the access to and transfer of environmentally sound technologies and the corresponding know-how to developing countries on favourable terms, including on concessional and preferential terms, as mutually agreed, taking into account the need to protect intellectual property rights, as well as the special needs of developing countries for the implementation of Agenda 21.

32. Urges Governments, industry and international organizations to promote technology transfer and research cooperation to foster sustainable agricultural practices which promote efficient water use and reduce pollution of surface water and groundwater. These technologies should include the improvement of crops grown on marginal sites, erosion control practices, and the adaptation of farming systems. They should also improve water use efficiency in irrigated areas and improve the adaptation and productivity of drought-tolerant crop species. Farmer participation in farm research, irrigation projects and watershed management should be encouraged. Research results and technologies should be available to both small and large producers.

33. Urges Governments to promote innovative approaches to technology cooperation projects involving partnerships between the public and private sectors within an effective framework of regulation and supervision.

34. Calls upon all relevant parties to develop and implement best practices and appropriate technologies, taking into account the local conditions, in the area of water development, management, protection and use. Codes of conduct, guidelines and other voluntary agreements, can enhance the positive role that industry and agriculture can play, and should cover the activities of companies operating and investing outside their home countries.

35. Encourages Governments to make the best use of national, regional and international environmentally appropriate technology centres. The use of local and traditional technology and knowledge should be promoted, and South/South cooperation should be encouraged.

36. Encourages Governments to develop programmes linked to education, especially those relating to water and land management. Water and land users and managers alike need to become more aware of the need to control wastage and factors affecting demand and supply, to realize the scarcity value of water, water-borne diseases and pollution, soil erosion and deterioration, sedimentation, and environmental protection.

37. Urges donor countries and international organizations to intensify their efforts and to accelerate their technical assistance programmes to developing countries, aimed at facilitating the transfer and diffusion of appropriate technologies. The United Nations system, as well as regional groupings, have an important role to play in facilitating the contact between those in need of assistance and those able to provide it. Less formal arrangements may also have a role to play.

D. Financial resources and mechanisms

38. The Commission reaffirms that, as stated in the Programme of Action for the Further Implementation of Agenda 21, the current intergovernmental process on freshwater resources can only be fully fruitful if there is a proved commitment by the international community for the provision of new and additional financial resources to developing countries, in particular to the least developed countries, for the goals of this initiative. Such financial resources, from all sources, need to be mobilized for the development, management, protection and use of freshwater resources if the broader aims of sustainable development are to be realized, particularly in relation to poverty eradication. The effective and efficient use of resources currently allocated to the freshwater sector is also important and could contribute in helping to increase the flow of finance from both the public and private sector.

39. Official development assistance (ODA) should be provided, inter alia, for, and compliment, programmes and frameworks for promoting integrated water resources development, management, protection and use that (a) meet basic needs; (b) safeguard public health; (c) promote sustainable development and conservation and sustainable use of ecosystems; and (d) build capacity. Donors, including multilateral donor institutions, should be ready to continue, or even reinforce, the support for programmes and projects in the water sector which will contribute to eradicating poverty. In this context, the Commission recalls that all financial commitments of Agenda 21, particularly those contained in chapter 33, and the provisions with regard to new and additional resources that are both adequate and predictable need to be urgently fulfilled. Project supported by donors should, where appropriate and possible, become financially self-sustaining. Donors should also continue to support the freshwater issues that are related to

desertification, loss of biodiversity, loss of wetlands, drought, floods, and climate change.

40. The private sector represents one of the growing sources of investment in the water sector. Local and national water management systems should be designed in ways that encourage public/private partnerships. It is important to ensure that water management systems are organized so that they will be sustainable and, once established, can support themselves. It is important to encourage the participation of the private sector within the framework of appropriate national policies. The adoption of enabling financial frameworks contributes to promoting the mobilization of private sector finance. ODA has an important role in assisting developing countries to adopt appropriate policy frameworks for water resources management.

41. For developing countries, the role of Government regulation in the allocation of freshwater resources remains important. Resources should be allocated and costs met in an accountable and transparent manner. Costs should be covered either through cost recovery or from public sector budgets. Cost recovery could be gradually phased in by water utilities or the public authorities, taking into account the specific conditions of each country. Transparent subsidies for specific groups, particularly people living in poverty, are required in some countries. Governments could benefit from sharing experience in this regard. Incentives may be necessary to promote land use practices appropriate to local conditions in order to protect or rehabilitate freshwater resources of particularly sensitive areas, such as mountainous regions and other fragile ecosystems.

The Commission on Sustainable Development:

42. Invites Governments to strengthen consultative mechanisms between bilateral and multilateral donors and recipient states aimed at improving or preparing schemes for the mobilization of financial resources in a predictable manner, for meeting the need of priority areas based on local and national programmes of action, with a special focus on integrated water resource development, management, protection and use while recognizing the needs of vulnerable groups and people living in poverty.

43. Calls for initiatives to be undertaken to help identify and mobilize more resources human, technical (know-how) and financial and take into account the 20/20 initiative, especially in the programme of poverty eradication in accordance with national policies and in the light of specific provisions and commitments on resources related to water issues made at recent United Nations conferences. A fundamental aim must be to promote the generation of the resources needed for economically and environmentally sound water supply and recycling, irrigation, energy, sanitation and water management systems, including the control of aquatic weeds, especially water hyacinths, and their efficient and effective deployment.

44. Invites Governments to allocate sufficient public financial resources for the provision of

safe and sustainable water supply and sanitation to meet basic human needs and for waste-water treatment. These resources should be complementary to the technical and financial support of the international community.

45. Urges Governments, when using economic instruments for guiding the allocation of water to take into particular account the needs of vulnerable groups, children, local communities and people living in poverty, as well as environmental requirements, efficiency, transparency, equity, and in the light of the specific conditions of each country, at the national and local levels, the polluter-pays principle. Such instruments need to recognize the special role of women in relation to water in many societies.

46. Urges Governments to initiate a review of existing financial support arrangements in order to enhance their efficiency and effectiveness. Such a review should aim at the mobilization of financial resources from all sources, particularly international financial resources, in a predictable manner, based on local and national action plans with a specific focus on integrated water resources development, management, use and protection programmes and policies. In this context, both formal and informal arrangements could have a role to play. International financial support will continue to be important to the development of local and national water management systems. Governments, with the technical and financial support of the international community, need to promote the economic, social and environmental values provided by ecosystems and examine the short-and long-term cost of their degradation.

47. Calls upon the international community to intensify its efforts and to consider new initiatives, within appropriate existing mechanisms, for mobilizing financial resources to promote efforts of developing countries in the integrated management, development, distribution, protection and use of water resources. Particular attention should be given to the following aspects:

(a) Promoting mcre effective donor coordination and more effective and creative use of existing resources;
(b) Generation of new and additional financial resources from all sources;
(c) The identification of appropriate sources of direct grants and loans in concessional terms;
(d) The quantification of the resources required to meet the needs of developing countries;
(e) Resources contributions by industrialized countries and international financial institutions, including regional institutions;
(f) Formulation of financial strategies which include possible partnerships with non-governmental organizations, the private sector and the promotion of conditions for increased private financial flows;
(g) The strengthening of consultative mechanisms, especially at sub-regional and regional levels, by Governments and the international community aimed at making freshwater a development priority and at improving dialogue between industrialized

and developing countries in a well targeted and predictable manner, based on national actions and plans, with a special focus on sustainable and integrated water resource management that recognizes the needs of all stakeholders, especially vulnerable groups and people living in poverty. This could include exploring the potential of new financial arrangements.

FOLLOW-UP AND ASSESSMENT

The Commission on Sustainable Development:

48. Invites Governments to continue to provide voluntary national communication or reports on actions they have undertaken towards the development and implementation of national strategies and programmes in integrated water resource development, management and protection. Requests the Secretariat to continue collecting, analysing and disseminating national information on this implementation and to ensure that data is gender differentiated whenever possible. Also requests the secretariat, in reporting to the commission, to make a more comprehensive use of the information already provided by Governments through their national reports and to promote exchanges of such information and further develop relevant databases.

49. Encourages Governments to work together at appropriate levels to improve integrated water resource management. The overall aim should be to ensure effective arrangements for cooperation between Governments to promote the implementation of policies and strategies at local and national levels. Possibilities should also be identified for joint projects and missions.

50. Recognises the important tasks for UN agencies and programmes and other international bodies in helping developing countries to implement their integrated water resources development, management and protection programmes and policies. It invites the Subcommittee on Water Resources of the Administrative Committee on Coordination, as task manager for Chapter 18 (freshwater) of Agenda 21, to make its work more transparent through, inter alia, regular briefings to Governments, to enhance coordination within the United Nations system and to accelerate the implementation of chapter 18 by considering action to, inter alia:

(a) identify gaps or inconsistencies in the implementation of programmes of its constituent organizations, by assessing the main features and effectiveness of the implementation of those activities, and ensure that the mainstreaming of gender perspectives is appropriately included;
(b) considering ways of increasing efficiency in programme delivery and possibilities for joint programming;
(c) explore the potential of cooperation arrangements and, where appropriate, taking into account the experienced gained in existing programmes in the United Nations system.

51. Invites the Secretary-General to provide a report to the Commission prior to its 8th session on progress by the Subcommittee on Water Resources of the Administrative Committee on Coordination, as task manager of chapter 18 of Agenda 21, on the activities in the above paragraph.

52. Stresses the importance of coordination of policies and activities of the specialized agencies and other bodies of the United Nations system related to freshwater, including clean and safe water supply and sanitation, and given the seriousness of the situation, emphasizes the need to provide close attention to the effects of disposal of toxic substances, including arsenic contamination of drinking water supplies, and persistent organic pollutants upon water resources, as recommended by the ECOSOC at it 1997 substantive session.

53. Invites the United Nations Environment Programme (UNEP), in collaboration with other relevant United Nations bodies, to play a vital role in providing inputs through the provision of technical and scientific advice on environmental aspects of the sustainable development of freshwater resources. In the field of freshwater, UNEP could focus on assisting countries, especially developing countries, in strengthening their ability in this regard, in technology transfer and environmental institutional strengthening and on responding to requests for assistance in strengthening integrated river basin management. The potential of the Global Environment Monitoring System (GEMS) and other relevant global monitoring networks should be fully utilized. Such activities would provide an effective contribution to the work of the Commission.

54. Encourages Governments in cooperation with relevant organizations to organize meetings aimed at identifying problems to be resolved, articulating priorities for action, exchanging experience and best practices and to facilitate progress in implementing this decision. Such meetings are invited to inform the Commission on their conclusions in order to contribute to its work.

55. Recognises the need for periodic assessments of the success of strategic approaches to the sustainable development, management, protection and use of freshwater resources in achieving the goals described in chapter 18 of Agenda 21 and for a global picture of the state of freshwater resources and potential problems.

56. Invites the Subcommittee on Water Resources of the Administrative Committee on Coordination, as task manager for Chapter 18 (freshwater) of Agenda 21, to arrange the compilation and publication of such assessments.[1]

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[1] The 1977 United Nations Water Conference (Mar del Plata, Argentina), the 1990 Global Consultation on Safe Water and Sanitation for the 1990s (New Delhi, India), the 1990 World Summit for Children (New York, USA), the 1992 International Conference on Water and the Environment (Dublin, Ireland), the

1992 United Nations Conference on Environment and Development (Rio de Janeiro, Brazil), the 1994 Ministerial Conference on Drinking Water Supply and Environmental Sanitation for the 1990s (Noordwijk, The Netherlands), the 1994 International Conference on Population and Development (Cairo, Egypt), the 1994 Global Conference on the Sustainable Development of Small Island Developing States (Bridgetown, Barbados), the 1995 World Summit for Social Development (Copenhagen, Denmark), the 1995 Fourth Action for the Protection of the Marine Environment from Land-based Activities (Washington, USA), the 1996 Second United Nations Conference on Human Settlements (Istanbul, Turkey), the 1996 World Food Summit (Rome, Italy) and the 1997 Nineteenth Special Session of the United Nations General Assembly (New York, USA).

All references in the present report to the platforms for or programmes of action of major conferences should be considered in a manner consistent with the reports of those conferences.

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