GUIDELINES OF LAKE MANAGEMENT

Volume 1

Principles of Lake Management

Editors:

S.E. Jørgensen and R.A. Vollenweider

International Lake Environment Comittee
United Nations Environment Programme

FOREWORD

Genady N. Golubev
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This book has been written as an attempt to explain the concept of Environmentally Sound Management and Development of Lakes. Our lives depend on both natural lakes and artificial reservoirs because they provide drinking water for millions, water for agricultural and industrial development and they provide unique recreational opportunities.

Many problems, however, arise from the process of development itself. Agricultural growth together with the construction of irrigation and drainage systems, the cleaning of forests, the building of factories and the use of fertilizers and pesticides - all may cause environmental damage to the lakes and lake basins; An advanced stage of lake eutrophication is virtually irreversible; Consequently environmental problems relevant to the lake regime need to be solved at a very early stage.

Management of lakes should be considered as a component of sustainable development of any country. Efforts to manage lakes and their watersheds in an environmentally sound way form an important part of the activities of United Nations Environment Programme. Nationally adapted and locally appropriate policies and guidelines for the environmentally sound management of the lakes are needed everywhere.

For their implementation this comprehensive book will hopefully form a relevant working framework; nevertheless the dedication of a limnologist who wrote it will amount to nothing unless the conclusions are ultimately translated into hard concrete action at individual lakes.

The designations employed and the presentation of material throughout this publication do not imply the expression of any opinion whatsoever on the part of U.N.E.P. concerning the legal status of any country, territory, city or area of its authorities, or concerning the delimitations of its frontiers or boundaries.

FOREWORD

The traditional friendly relationship between lakes and humankind, is now being jeopardized by unbalanced development of our civilization. Due to the misuse of surrounding lands the increased sediment inflow has filled a large number of natural and man-made lakes to the extent of completely diminishing their utility value. Toxic chemicals produced or used in watersheds have contaminated lake water, bottom sediments and fishery products and endamaged the use of these resources. Nutrients contained in industrial, agricultural and domestic wastewaters have caused the eutrophication of lake water, completely changing of the aquatic ecosystems by the explosive overgrowth of planktonic and other plants and degrading the quality of the water we use. The acid rain, which is a result of accelerated air pollution with oxides of sulphur and nitrogen, has also been an important factor leading to the drastic decline of lake productivity in certain parts of the world.

This degradation of lake environments and resources is now a world-wide issue. Efforts urgently have to be made to restore the friendly coexistence of lakes and humankind through appropriate management of lake/watershed systems to assure the sustainable use of their resources.

In view of the scarcity of international bodies devoted to this specific issue, the International Lake Environment Committee (ILEC) was founded as a non-governmental organization of scientific and managerial experts aiming at contributing to the promotion of environmentally sound management of lakes and their resources through intellectual non-profit activities. ILEC initiated its operation in 1986 in close cooperation with international agencies such as the UN Environment Programme, the UN Centre for Regional Development, the International Society of Pure and Applied Limnology, etc., as well as the government of Shiga Prefecture, Japan, and other governmental and non-governmental bodies. At its foundation it was a voluntary organization, but was later reorganized as a juridical corporation providing the original committee the status as its Scientific Committee. The ILEC's activities are currently concentrated on the four following subjects: the preparation of guideline books on reasonable lake management principles, the compilation of world lake environment data, the promotion of relevant traning courses and workshops, the provision of support to the Conference on the Conservation and Management of World Lake Environment which has been and will be held biennially since 1984.

The members of ILEC Scientific Committee are very pleased to see the publication of this book as the initial output of the Joint UNEP/ILEP Project, *"Promotion of Environmentally Sound Management of Lakes"* , which includes the first and third subjects of ILEC's activities. We should be very pleased if this book proves useful for decision makers, development planners and environment managers of the world, particularly in developing countries.

Representing ILEC in expressing its heartfelt thanks to Dr. Mostafa Tolba, Executive Director, and other staff of UNEP for their continuous encouragement and support to the present publication programme.

March 1988
Otsu, Shiga

Tatuo Kira
Chairman
Scientific Committee of ILEC

CONTENT

PART A: GENERAL PRINCIPLES

PART B: CASE STUDIES

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PART B: CASE STUDIES

PART A

GENERAL PRINCIPLES

This part of the book will present the general principles and concepts of lake management. A detailed approach to concrete lake management problems - eutrophication, acidification, fishery yield etc. will be presented in later volumes of this guideline book series. This book should therefore be considered as a presentation of the basis for the other guideline books, as it attempts to touch on all aspects of lake management: the ecological, limnological, technological, economic and social ones.

The multidisciplinary and holistic views of lake management are emphasized in the introduction. It may also be called the macroscopic view, as not only a single lake components or even the lake, but the entire watershed is considered.

Chapter 2 presents the basic ecological concepts of lake management. The chapter is named ecosystem concepts with emphasis on system. The chapter reviews how a lake is working as an *ecosystem.*

Chapter 3 summarizes the problems of lakes and reservoirs. Later volumes in the guideline series will focus on particular problems such as eutrophication, toxic substances and fishery. Therefore, this chapter will not deal with the problems in detail but only present some general principles and a summary on lake management problems.

After recognition of the problems must follow an assessment of the problems. Consequently, chapter 4 surveys qualitative and quantitative assessment methods as the next step.

In chapter 5 a quantitative assessment of the sources to the problem by using mass balances is presented, followed in chapter 6 by a review of modelling, which is a more and more widely used tool in lake management since it enables the scientist and the manager to overview complex systems and problems.

Chapter 7 reviews the remedial techniques, that we have at disposition of an environmentally sound solution to the problems. The chapter deals not only with environmental technology but also with the ecological engineering methods, that may be applied to solve some of the problems for instance those related to the non-point sources or to carry out lake restoration.

The last chapter of this part focuses on planning and management of comprehensive environmental planning. This chapter touches on the social-economic aspects of lake management and present also the application of environmental impact assessment (EIA) as a useful tool in environmental management and planning. The holistic, macroscopic views and the importance of considering all aspects from ecological to social-economic simultaneously are particularly emphasized in this chapter.

The measurements and samplings which need to obtain a first information on lake structures and functions are summarized in a flowchart presented in the appendix.

CHAPTER 1

GENERAL INTRODUCTION

Lakes are open systems i.e. they exchange energy and mass with the environment. The state of the lake is obviously strongly dependent on these exchange processes, which are described by use of what is called *external variables or forcing functions* (they describe the forces on the lake as function of time). Forcing functions are either controllable or noncontrollable. The latter are for instance precipitation, wind, solar radiation, etc., while the controllable ones are, for instance, in- and outflow of water, nutrients and toxic substances.

The state of the lake is described by use of *state variables or internal variables* . Examples are phytoplankton-, nutrients- and fish concentrations.

The core of lake management is to find the relations between the forcing function and state variable and to use the knowledge of these relations to change the controllable forcing function to achieve a desired state of the lake. The tools (quantification methods, models) implemented to obtain the relationships are described in chapter 5 and 6, while the method (remedial techniques) available to change the controllable forcing functions are mentioned in chapter 7. The relations of these concepts are illustrated in Fig. 1.1.

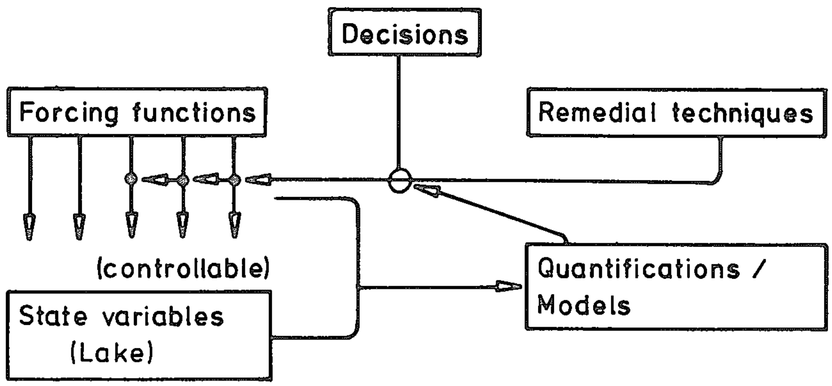


Figure 1.1 Relations of the concepts given in the text.

However, lakes are integrated parts of the entire watershed. As they are open systems the watershed will influence the lake, and the lake will influence the watershed. It is therefore hardly possible to manage the lake as a system, separated from the watershed and its environment. This emphazises the need for system approaches and modelling, as you need to survey a complex ecosystem and even an entire watershed. Therefore, good management strategies do not imply that a problem is analyzed as an isolated matter, but it is always required to relate environmental problems to the entire lake **and** its environment. Fig. 1.2. illustrates an example of bad or lack of management, which unfortunately is often seen in practice. A lake is used for the production of drinking water and the water authorities may put a lot of effort into the production of high quality drinking water. Separately from this issue, the waste water authorities may be concerned with the influence of waste water on the water quality of the lake. No coordination between the 2 authorities takes place. If good management is used first of all, a coordination between the production of drinking water and treatment of waste water must take place.

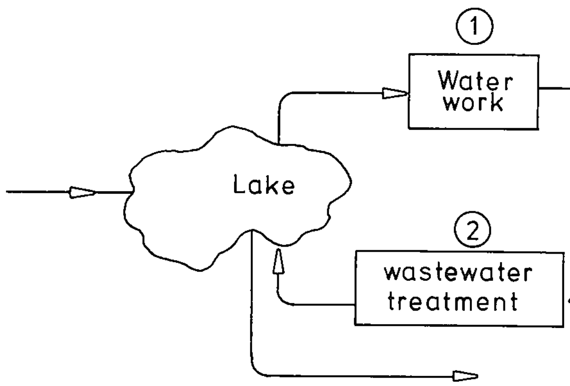


Figure 1.2 An example of bad lake management.

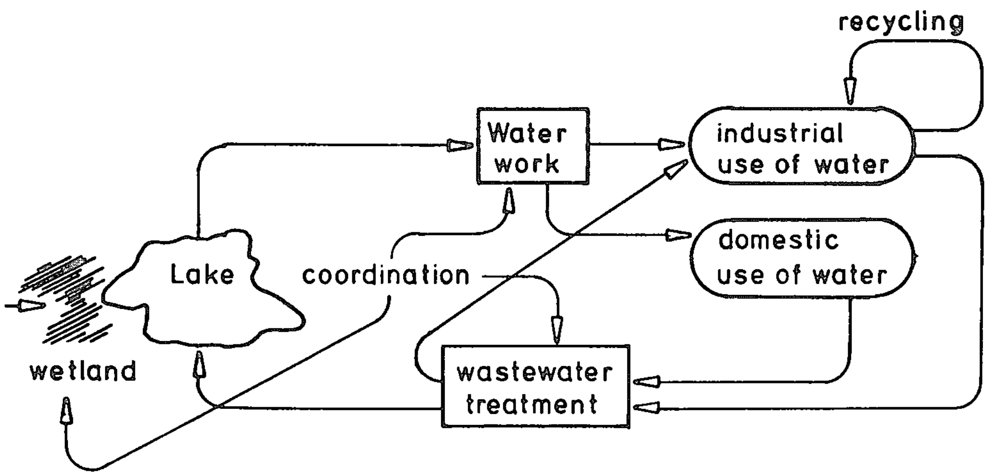


Figure 1.3 Illustration of a good management strategy.

Furthermore, it should be considered to recycle the water partly. Some industries may be able to recycle their water or use partly treated waste water and thereby decrease the cost of drinking water and treatment of waste water and even the impact om the ecosystem. This better management strategy is illustrated in Fig. 1.3.

Another illustration of the difference between good and bad management strategy is shown in the same figures. In Fig. 1.2. the emission of nutrients from agriculture is not considered. Consequently, the lake water will by very eutrophic and/or it is required to apply a very advanced and expensive waste water treatment. In Fig. 1.3. wetlands are maintained along the shores of the tributaries to work as traps for the nutrients coming from nonpoint sources. This will reduce the need for advanced waste water treatment and also for a more comprehensive treatment of the portable water.

The conclusion of these considerations is clear: go a step backwards and use a *"macroscope"* to consider the entire ecosystem and its environment as one system and optimize on that level.

The importance of this approach to lake and reservoir management must be assessed from two standpoints, with regard to theoretical and applied objectives:

1) With respect to the importance of the catchment area as the site of the principal sources supplying the lake, not only in hydrological and energetic terms but also in chemical, that is to say, nutrient and toxic substance terms.

2) With respect to the goals of management taking into account the relationship existing between the properties of the catchment area and the trophic-productive level of a lake system situated in a given catchment area.

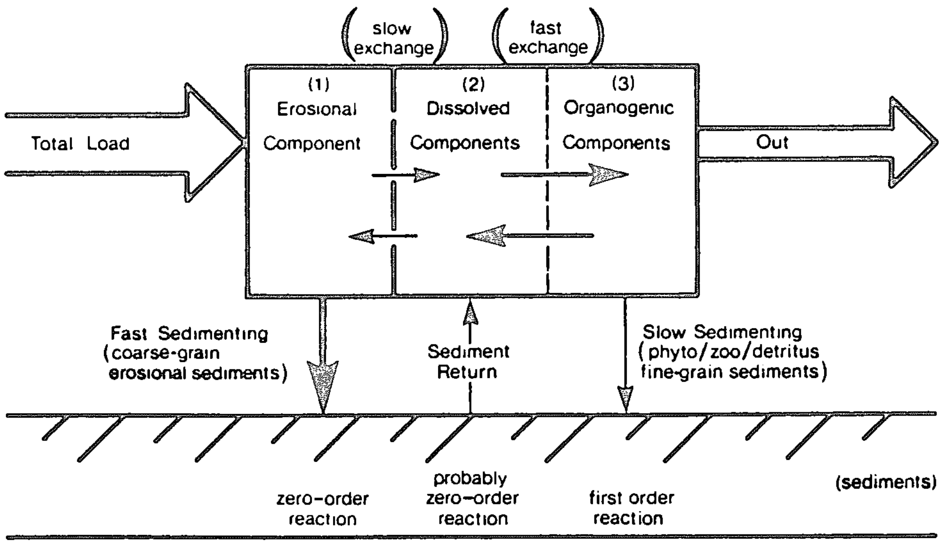
The underlying concept which meets these premises is that of "loading" and has given rise to that of "loading tolerance" of a lake system in terms of its morphological, hydrological and overall limnological conditions.

The diagram presented in Fig. 1.4 illustrates the connection between the external load and the major processes and compartmental routes inside the lake. While classical limnology dealt mainly with compartments and processes inside a lake, this diagram attempts to emphasize that the external nutrient load is the food of the cyclical processes within the system, that is to say, the system is preserved or changed, precisely as a function of this food. Therefore, loading as a concept takes on a position of fundamental importance both in theoretical research and in practice.

It follows furthermore from this approach to the problem that - to understand the operation of the system, lake or impoundment, in its totality - it is necessary to describe its dynamics not only in qualitative terms but **in terms of mass flow and balance**, that is to say in exact terms of how much material enters, leaves and remains in circulation.

From the foregoing, we may already attempt an initial conclusion of a practical nature. A lake system with a short water renewal time will be balanced - following a variation in the external nutrient load - at a trophic level different from that of a lake system with slower renewal. This is due to the fact that the **retention time of the substances within the production cycle** will be longer, the longer the renewal time of the body of water. Therefore, a lake system with slow water renewal will be more susceptible to eutrophication, toxic substances and pH-changes, in relation to a given load, than a system with rapid water renewal. The quantitative aspect of this concept will be considered below.

CONCEPTUAL MODEL



Reaction (1) ⇆ (2) Influences Lake Content only transitorily

Reaction (2) ⇆ (3) Deciding for Lake Content yet cannot be defined at a time resolution basis of 1 year

Figure 1.4 Conceptual model, illustrating the connection between the external load and the major processes and compartmental routes inside the lake.

Implicitly, Fig. 1.4 provides additional hints for practical eutrophication management for such cases where external nutrient load control is impossible or only partially possible. Eutrophication can partially be controlled by slowing down or altering lake internal mechanisms and processes. Alternative interventions into lake dynamics can be quite varied, can be applied singly, or in combination, including external load manipulations.

CHAPTER 2

ECOSYSTEM CONCEPTS

2.1 INTRODUCTION

A scientific approach to lake and environment management is concerned with the study of **structures** and **functions** of aquatic ecosystems. The study of physical, chemical and biological parameters reveals the importance of the structures for understanding the functions of the ecosystem. Structure means e.g. the distribution of nutrients in the water column and the pattern of phytoplankton and zooplankton connected with the chemical background. From the functional point of view the primary production of the phytoplankton, metabolically coupled with the supply of limiting nutrients is one of the key processes enabling aquatic life. Metabolic activities of microorganisms are also of eminent importance for building up definite structures and functions in nature.

The term **ecosystem** was first proposed in 1935 by the British ecologist A.G. Tansley, but the **concept** is much older. Thus Karl Möbius, Professor of the University of Kiel (Germany), in 1877 discussed about the community of organisms of an oyster reef as a "biocoenosis", and in 1887 the American S.F. Forbes wrote his classic essay on the lake as a "microcosm". The term "ecosystem" has now asserted worldwide and has been assimilated in all languages.

Ecosystems are forming a very complex coupling of components to form functional units. Therefore, it appears useful, first of all to discuss the different components in order to make the complexity transparent.

2.2 THE ENVIRONMENT

Freshwater ecosystems occupy a relatively small portion of the surface of the earth in comparison to marine and terrestrial habitats (see Table 2.1). The amount of freshwater including the glaciers of the Arctic and Antarctic regions accounts for only 2.4% of the total global amount of water. 97.6% belong to the vast amounts of water in the oceans, which cover 71% of the surface of the earth. Lakes contain only the very small part of about 0.01% of the global amount of water.

Table 2.1 Water of the world

World Water Reserve	1358.8 mill. km^3
Oceans	1321.3 mill. km^3
Underground Salt Water	4.2 mill. km^3
Freshwater Reserve	33.3 mill. km^3
- in Polar Ice & Glaciers	29.1 mill. km^3
- Groundwater	4.1 mill. km^3
In Rivers and Lakes	0.1 mill. km^3
Reserve in Rivers and Lakes	139200 km^3
- Atmosphere 9.3%	12950 km^3
- Rivers 0.9%	1250 km^3
- Lakes 89.8%	125000 km^3
Laurentian Great Lakes	22725 km^3
(Superior, Michigan, Huron, Erie, Ontario)	(18.2%)

Globally the water balance is dominated by the fact that more water evaporates from the ocean than is returning via precipitation. The oceanic evaporation supplies 86-88% of the total global evaporation, whereas the area of the oceans amounts only 71%. Thus, the oceanic evaporation is a regulator of the global water balance:

	continents	oceans
precipitation	100	411
evaporation	63	448

(figures in 10^3 km^3/year, after Flohn, 1973)

The water itself has got several unique thermal properties which are decisive for the special features of freshwater ecosystems:

1. **Water has its greatest density at 3.98°C**, it expands and becomes lighter both above and below this temperature. This unique property connected with the dipol character of the water molecule is the reason for freezing of lakes from the surface and prevents lakes from freezing solid.

2. **High specific heat**, which means that a relative large amount of heat

is required for changing the temperature of water. Thus, temperature changes are smaller and occur more slowly in water than in air. This "temperature buffer" has great importance for all biological processes. 4.18 kJ is required to raise one kg of water one degree (between 15° and 16°). Only ammonia and a few other compounds have values higher than 4.18!

3. During evaporation 40.66 kJ/mole (at 100°C) or 44.02 kJ/mol at 25°C are absorbed. That is **the highest known latent heat of evaporation**. Therefore, a major part of the incoming solar radiation is dissipated in the evaporation of water.

Temperature changes produce characteristic patterns of stratification and circulation which greatly influences the aquatic life (compare 2.8).

2.3 STRUCTURE

The major components comprising the **structure** of a freshwater ecosystem are the following (after Odum, 1971):

<u>Abiotic Components</u>

1. **Inorganic substances** involved in material cycles.

Total ionic salinity of surface waters.

The ionic composition of surface waters is dominated by four major cations, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and four major anions, HCO_3^-, CO_3^{2-}, SO_4^{2-} and Cl^-. These usually constitute the total ionic salinity of the fresh waters.

In open lakes of the temperature zone calcium and bicarbonate ions are prevailing:

Cations: Ca > Mg > Na > K

Anions: $HCO_3^- > SO_4^{2-} > Cl^-$

There are, however, frequent deviations from these proportions in drainage basins of igneous source materials and soft waters. The specific conductivity is closely proportional to concentrations of the major ions and changes of conductivity reflect proportional changes in ionic concentrations.

Three major mechanisms control globally the **salinity** of surface waters: weathering of rocks, atmospheric precipitation and the relation between precipitation-evaporation. Figure 2.1 gives a diagrammatic representation of the general processes controlling the salinity of surface waters of the world.

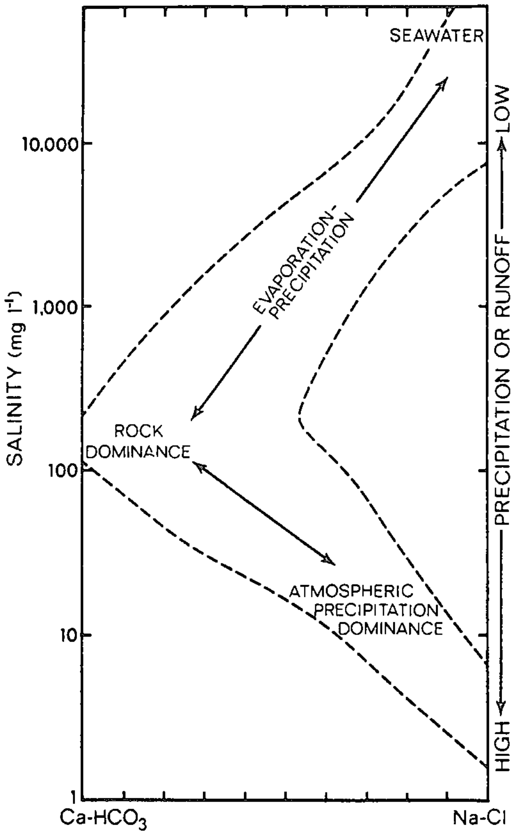


Figure 2.1: Diagrammatic representation of the general processes controlling the salinity of surface waters of the world. (After Wetzel, 1983)

Waters dominated by rock weathering are usually rich in calcium and bicarbonate. Climate, basin-relief, and the composition of rock material have a dominant influence on the composition of water. Tropical humid areas of South America and Africa have rainwater with a high ionic composition. This atmospheric precipitation is dominating the salinity as well as low rainfall and high evaporation in hot and arid regions.

<u>Nutrients and Trace Elements</u>

The amounts of nitrogen and phosphorus are widely significant for the productivity of lakes and streams. Phosphorus is commonly the limiting factor for productivity due to its small natural supply. These major nutrients and numerous trace elements (e.g. iron, manganese, molybdenum, zinc) are of essential biological importance but do not contribute substantially to the total salinity.

2. Organic Components
Dissolved carbohydrates, proteins, humic substances, pigments, vitamines comprise the major organic components of water. They are mainly produced by metabolic processes within cells and can play an important role in the aquatic ecosystem as extracellular dissolved organic matter (DOM), released by autolysis or excretion. Thus, the excretion of amino acids by zooplankton may be temporarily a major source of dissolved organic matter (DOM). Free enzymes (exoenzymes) are of importance, e.g. the phosphorus cycle can not be understood without consideration of free phosphatases.

3. Climatic Regime
The temperature pattern determines the type of stratification, while light is controlling the photosynthesis. Therefore, the climate is of importance for lake ecosystems.

Biotic Components

4. Producers, autotrophic phytoplankton and higher plants (macrophytes), produce biomass from simple inorganic substances.

5. Macroconsumers, zooplankton and fishes, feed on other organisms or particulate organic matter (detritus).

6. Microconsumers, heterotrophic organisms, chiefly bacteria and fungi, are responsible for the degradation of the particulate or dissolved organic substrate produced by autotrophic processes or coming from allochthonous sources. Thus, from a trophic point of view the biomass can be separated in two components, **autotrophic** and **heterotrophic**. They are metabolically coupled through a food web.

2.4 FUNCTION

STRUCTURE is concerned with the standing crop and distribution pattern of abiotic and biotic components.

FUNCTION is concerned with **rates**. We are e.g. not interested only in the amount of inorganic phosphate which is present at the time, but also in its turnover rates.

Often we can determine rates rather simply by the same methods we use for the determination of concentrations and biomasses. **Rates are essential for understanding the dynamics of ecosystems.**

An ecosystem may be analyzed from the **functional point of view** in terms of the following:

1. **Energy circuits** (all life processes are accompanied by energy transfers!)
2. **Nutrient cycles** (biogeochemical cycles of the major nutrients).
3. Distribution pattern and productivity of the **organisms** in space and time.
4. **Food chains** (grazing food chain and detritus food chain).
5. **Control** (cybernetics, regulation of metabolism).

The **ECOSYSTEM is the basic functional unit in ecology**, and includes both organisms and abiotic environment. Both influence the properties of the other.

2.5 THE BASIC DIFFERENCE BETWEEN AQUATIC AND TERRESTRIAL ECOSYSTEMS

Aquatic and terrestrial ecosystems have basically the same structure and function, but there is a striking difference: The producers in the **hydrosphere** mostly belong to phytoplankton and are almost exclusively unicellular algae. Their lifecycle and turnover time (ratio of biomass to production) are measured in hours or days. The producers of the **litosphere** are mainly higher plants with a high biomass and long turnover time: in forests the turnover time is measured in years. The difference between structure and function of the hydrosphere and the litosphere is shown in the following table:

Table 2.2
Estimated phyto-biomass in the litosphere and hydrosphere (terrestrial and aquatic ecosystems) (from Walter, 1976)

	area 10^6 km^2	biomass 10^9 t	annual production 10^9 t
Litosphere	149	2.000	150
Hydrosphere	361	2.8	60

The ratio of biomass in the litosphere and hydrosphere is 700:1, while the ratio of production is only 2.5:1. It means that the specific productivity (productivity per unit biomass) in the aquatic ecosystems is much higher than in the terrestrial ones.

2.6 LAKE REGIONS OF TEMPERATE LAKES

Open-water zones. The **limnetic** or **pelagic** zone of the lake is devided in three regions. The so-called **trophogenic** zone is the well illuminated, warm upper layer where photosynthesis by phytoplankton algae prevails. The trophogenic zone is defined largely by the **epilimnion**, but is not identical to it. A high absorption of light will result from high phytoplankton concentration and the photysynthetically available radiation (PAR) will not reach the lower boundary of epilimnion, while PAR, in clear water lakes, may penetrate the epilimnion and parts of the hypolimnion. Thus, the boundary of the trophogenic-tropholytic zones is a function of light penetration. It is the **compensation depth** where photosynthesis is matched by respiration (Fig. 2.2).

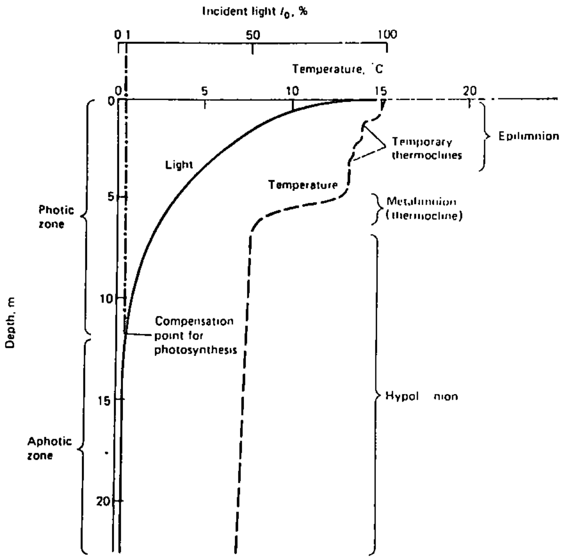


Figure 2.2 Structure of a stratified, temperate lake. The temporary thermoclines are caused by heating on calm days, they are destroyed each night by convective cooling or by wind. The rather low transparency indicates that the lake is eutrophic (high biomass). For further explanation see text. (From Goldman & Horne, 1983)

At the bottom of the lake lies a body of colder body of heavier, stagnant water, which is only little affected by wind action - the **hypolimnion**. Between epilimnion and hypolimnion, where temperature drops rapidly with increasing depth, we find the **thermocline** (Birge, 1897). Corresponding to Birge's definition the thermocline is limited to a zone where the temperature drops at least 1°C by one metre. For further discussion compare Brønstedt & Wesenberg Lund (1911) and Hutchinson (1957).

Metalimnion and hypolimnion constitute the **tropholytic** zone where respiration and decomposition are predominating. Especially the **metalimnion** is a region of high heterotrophic bacterial activity. Organic material produced autotrophically in the epilimnion is decomposed in the metalimnion by bacterial populations of high biomass and special metabolic features. In stratified lakes of the temperate zone about 80-90% of the primary production are metabolized in the metalimnion. This high concentration of heterotrophic microbial activity in the metalimnion is caused by the enrichment of particulate organic material (POM) in the density gradient between epilimnic warm water and hypolimnic cold water.

The grazing by zooplankton and predation by fish are parts of the **food chain**, i.e. the transfer of food energy through the different trophic levels. At each transfer from one level to the next about 80 to 90% of the potential energy is lost. Food chains are in a very complex way interconnected with one another forming so called **food webs**. There are two basic types of the classical food chains:

The **grazing food chain** starts from phytoplankton, goes to grazing zooplankton and then to fishes as top-carnivores. The **detritus food chain** starts from particulate (or dissolved) dead organic matter which are degraded in a very complex way by microorganisms. These are excellent food for detritus-feeding organisms, which are eaten their predators. The whole complexity of the food chains is still not known in details. Apparently, small heterotrophic nanoflagellates and ciliates are playing an important role in food webs. The grazing impact of this small zooplankton on bacteria is unexpected high. The consumption of bacteria may be in the same order of magnitude as the bacterial production, which on the other hand may be occasionally as high as the autotrophic production.

Benthic zones and benthos. The community of bottom dwelling organisms is termed benthos. The **littoral** region of the benthic zone extends from shore line to a depth where rooted aquatic plants disappear. The littoral benthos is composed of a high diversity of many taxonomic groups and species with a considerable annual production in contrast to the deeper sublittoral zone. Also the heterotrophic microbial activity in littoral sediments is high, e.g. measurements of heterotrophic potentials indicate a rapid turnover of particulate and dissolved organic matter. Thus, the littoral region as the borderline between the terrestrial catchment area and the lake ecosystem is of high importance for lake metabolism.

In the **profundal** zone of deep temperate lakes with summer stratification we meet the following conditions are met: nearly uniform temperature throughout the year, about 4°C. Oxygen is scarce or totally depleted. Hydrogen-sulfide and methane may be present if the lakes are productive (eutrophic). The profundal fauna is improverished under these conditions. Nevertheless the profundal zone is a region of high microbial activity, connected with the entire lake metabolism. In oligotrophic lakes oxygen is present in the whole water body - also during the summer stratification.

2.7 LAKE TYPOLOGY

Table 2.2
Features contrasting oligotrophic and eutrophic lakes - factors contributing to or resulting from the two types (modified from Thienemann, 1925).

Oligotrophy	Eutrophy
Deep and steep-banked	Shallow, broad littoral zone
Epilimnion volume relatively small compared with hypolimnion	Hypolimnion volume relatively small compared with the epilimnion
High transparency	Limited transparency
Water poor in plant nutrients	Plant nutrients are abundant
Sediments low in organic matter	Profundal sediments an organic copropel
Oxygen always abundant at all levels	Oxygen depleted in hypolimnion during summer
Littoral plants limited	Littoral plants abundant
Phytoplankton quantitatively poor	Abundant phytoplankton
Water blooms of bluegreen algae lacking	Water blooms common
Profundal bottom fauna diverse; intolerant of low oxygen tensions	Profundal benthos poor in species which can survive in low oxygen
Profundal benthos quantitatively poor	Profundal benthic biomass great
Tanytarsus-type midge larvae in produndal benthos; Chaoborus usually lacking	Chironomus, the profundal midge larva; Chaoborus often present

Lakes in all regions may be classified based on productivity according to the oligotrophic - eutrophic series. A summary of features contrasting **oligotrophic** and **eutrophic** lakes is displayed in the Table 2.2 (after Cole, 1983):

A simple scheme (after Odum, 1971) may illustrate the essentials of lake typology with special focus on lake morphometry and nutrient loading, which presumes. a relationship between the quantity of nutrient entering a water body and the response in the production to that nutrient input. Fertile eutrophic lakes are typical for areas, where the soil is rich in nutrients. In nutrient poor regions, we find lakes of low productivity.

	Concentration of Nutrients Low	Concentration of Nutrients High
Shallow	Morphometric Eutrophy	Eutrophic
Deep	Oligotrophic	Morphometric Oligotrophy

Typically, **oligotrophic** lakes are deep and the hypolimnion is larger than the epilimnion. They have a low primary productivity. Deep lakes with rather high concentrations of nutrients can be temporary oligotrophic, if limiting nutrients, especially phosphate in the surface water are depleted and an exchange with the hypolimnetic nutrient rich water is prevented by the thermocline. Such lakes are temporarily "morphometric oligotrophic".

Eutrophic lakes are often more shallow. The internal loading of phosphorus from the sediment supplies the euphotic trophogenic zone continously with the limiting factor phosphate. Therefore, they have a greater primary productivity, plankton populations are denser and "blooms" are common. The general trend of increasing productivity with decreasing depth is apparent and can be demonstrated in temperate lakes by the relation between mean depth of a lake and the chlorophyll concentration (e.g. Thienemann, 1927; Vollenweider ed., 1982).

Concerning **primary production** the following characteristics of the basic two types of lakes - oligotrophic and eutrophic - may be emphasized:

1. The total biomass of phytoplankton determines the depth of the productive euphotic - layer of the lake. In **eutrophic** lakes we meet a high biomass, low transparency, high rates of photosynthesis near the surface of the lake, with light as a limiting factor. The biomass of

phytoplankton and the primary production are low in typical **oligotrophic** lakes of high transparency, but cover a greater depth than in eutrophic lakes.

2. The rate of photosynthesis is correlated with the biomass of phytoplankton. The development of the biomass is determined by the supply of nutrients, mainly phosphorus or nitrogen.

A special type of lake is the **dystrophic** or **brownwater** lake with high concentrations of dissolved humic acids, supplied to the lake from the environment. The relative resistant humic substances of terrestrial plant origin are the most important part of allochthonous organic matter.

Quite in contrast to temperate and dystrophic lakes behave **warm** lakes. These are lakes with surface temperatures in summer of about 25°C and a homogenous temperature after winter turnover of well above 12°C. Under the given climatic conditions light is not a limiting factor, the photosynthetically available radiation (PAR) going down to more than 20 m depth. The decomposition of organic compounds is fast and the whole metabolism in these lakes is very often accelerated: only very small amounts of dissolved organic matter (DOM) are found and these are in contrast to DOM of temperate lakes of low molecular weights. Similar conditions, with respect to organic compounds, may also be valid in **tropical** lakes.

Saline lakes

The climate influences markedly the balance between precipitation and evaporation and thereby the salinity. In arid areas where closed basins hold concentrated waters, the salinity is governed by inputs of dissolved ions from the catchment area and the degree of evaporation. Other factors of importance for salinity are temperature and wind. Weathering of rocks which may have an big influence on the composition of electrolytes in lake water, is accelerated by a warm climate. Wind influences the chemical composition of precipitation and sites of deposition. Saline lakes can be classified on the basis of dominating anions into carbonate, chloride or sulfate waters. The range of salinity is extremely high, up to 200,000 mg/l in the Great Salt Lake of Utah.

There exist at least three different types of sodium lakes of importance with preponderance of NaCl, Na_2SO_4 and the soda lakes sensu stricto characterized by $NaHCO_3$ and Na_2CO_3, termed alkali waters because of their high pH.

Water balance of lake basins

The rate of inflow from all sources and the rate of water losses determine the water balance of a lake. Water income to a lake includes several sources (after Wetzel, 1983):

a. Precipitation directly on the surface of the lake. Precipitation is especially important for the water balance of large lakes. The equatiorial Lake Victoria receives more than 90% of its water from precipitation on the surface.
b. Water from surface influents of the drainage basin. The amount of water runoff to a lake is highly variable and depends on the morphometry, nature of the soil and vegetation cover of the drainage basin. Most important is also the precipitation patterns: a high surface runoff can be caused by heavy rains in a relatively short time together with a heavy loading of nutrients as a result of soil erosion.
c. Groundwater seepage below the surface of the lake. Seepage of groundwater is a major source of water for kettle lakes formed by glacial activity and for lakes in rock basins. Groundwater may also enter the lake by distinct springs.

In **seepage lakes** water is lost by seepage into the groundwater through the basin wall. This makes the determination of water balance in these lakes very difficult. In open drainage lakes loss of water occurs by flow through an outlet.

2.8 CIRCULATION PATTERNS

In terms of the water circulation patterns most of the lakes belong to one of the following major categories, which, indeed, are only rough schemes of the real diversity.

1. **Dimictic lakes.** These lakes have two seasonal periods of circulation or overturns: in spring after icebreak and in fall when the temperature of the epilimnion drops and the homothermic water body of the entire lake is mixed. This circulation pattern is characteristic for temperate lakes.

2. **Warm monomictic lakes.** The water circulates freely in winter when, with sinking temperature, the surface water is sinking down. To this type of mixing belong lakes of temperate latitudes, mediterranean and subtropical climates. The temperature do not drop below 4°C.

3. **Oligomictic lakes.** Thermally stable tropical lakes with a very slow or rare mixing.

4. **Polymictic lakes** are characterized by irregular more or less continuous mixing periods depending on the lake morphometry and climatic conditions. To this type belong equatorial and high altitude lakes without severe temperature and density gradients. Tundisi (1984) emphasizes that the patterns of mixing are complex, and that diurnal patterns of water temperature and density may be more significant than seasonal patterns. Very little is known about, to what extent these diurnal fluctuations are essential for the functioning of this type of lakes in comparison to seasonal patterns.

5. **Meromictic lakes**. In contrast to holomictic lakes with a circulation of the entire water column, meromictic lakes do not undergo complete circulation: the surface water does not mix with lower water layers. The deeper part of the water, underlying the upper part is termed *monimolimnion* , underlying the upper *mixolimnion* (Findenegg, 1935; Wetzel, 1983). The reasons of meromixis are different. In **ectogenic meromixis** water of different salinity is intruded by some some external event into a lake. As result a superficial layer of less dense water is overlying the monimolimnion of more dense water of high salinity. **Endogenic meromixis** results from submerged saline springes delivering dense water into the deep parts of the lake. Accumulation of salts can also be due to biological activities when abnormal meteorological or morphometric conditions prevent full circulation of a dimictic lake. This type of meromixis is termed **temporary meromixis.**

2.9 BIOGEOCHEMICAL CYCLES

The chemical elements essential to life are circulating in the biosphere from environment to organisms and back to environment in a very complex way. These pathways are known as the **biogeochemical cycles**. The pathways of those elements and organic compounds, which are essential to all forms of production of biomass, can be termed **nutrient cycles**. Each cycle has two major pools:

1. the **reservoir pool**, a large, slow-moving components, and

2. the **exchange or cycling pool**, a small, metabolically active portion, exchanging rapidly between organisms and their environment. For example the cycling pool of phosphorus in lakes is much more important for continuous primary production than the reservoir pool.

Biogeochemical cycles in lakes are **controlled** by morphometry ("mean depth") of the lake, hydrography (residence time of water), loading from the catchment area and sinks (retention) on the one side, by the total biomass, their specific metabolic activity and the biochemical diversity of the populations on the other side. The **abiotic** and **biotic controlling factors** are strongly interrelated. The biogeochemical cycles within an ecosystem reflect the total metabolism of the system, including autotrophic and heterotrophic processes, anabolic (assimilation) and catabolic (dissimilation) pathways.

2.10 THE WATERSHED VIEW

As already mentioned, the biogeochemical cycles are partly determined by **external loading** of the lake ecosystem from the catchment area. Lakes are open systems with inputs and outputs. The external loading of nutrients is decisive for the productivity of a lake within the limits set by climatic conditions, residence time etc. for different areas at different latitudes. An increased production gives rise to oxygen depletion in the hypolimnion resulting in release of nutrients from the sediment. This supply of nutrients to the lake ecosystem constitutes the **internal loading**.

Vollenweider (1968) was the first to formulate quantitative loading criteria for phosphorus and nitrogen and expected trophic conditions in water bodies (nutrient loading concept). Because phosphorus is commonly the initial limiting factor, quantitative loading approaches and models relate mostly to phosphorus.

The quantitative determination of the external (L_E) and internal loading (L_I) is one of the most difficult problems of current research on eutrophication problems. This is valid especially in case of a "non point source loading" from diffuse sources, which is most important in intensively used agricultural districts. For example for Lake Grebiner See (Schleswig-Holstein, West-Germany), surrounded by strongly fertilized arable land and meadows, more than 95% of the annual phosphorus loading comes from non-point surface run-off from the watershed area (Ohle, 1982).

2.11 NITROGEN AND PHOSPHORUS AS LIMITING NUTRIENTS

N and P are taken up by phytoplankton at a mass ratio of averagely 7.2:1. If the available amounts differ widely from this ratio a limitation of the production is resulting. The critical N:P ration is about 10:1. From the comparative study of N:P ratios in algal cells in cultures and lake water, Forsberg et al. (1978) determined the role of these elements as growth limiting nutrients (Table 2.3).

Table 2.3.
Total-N:Total-P ratios and the role of these elements as growth-limiting nutrients in waste-water affecting lakes in relation to chlorophyll A levels

Total N/Total P	Growth-limiting nutrient	Chlorophyll A level mg/m^3
> 12	P	< 20
7 - 12	N and/or P	20 - 70
< 7	N	> 70

At	N:P >12	P is the limiting factor.
At	N:P < 7	N is potential growth limiting.
At	7 < N:P < 12	Both nutrients are non-limiting factors.

The N:P ratio in municipal waste water is 3:1, while non-point sources show a much higher ratio. Nitrogen may, therefore, often be the limiting nutrient in waste water loaded lakes. This does not imply that the eutrophication is better controlled by nitrogen removal. As phosphorus is more easily removed from waste water than nitrogen by chemical precipitation, and as a more significant part of the phosphorus is originated from the waste water than nitrogen, the eutrophication may often be controlled by phosphorus removal from the waste water.

2.12 HETEROTROPHIC BACTERIA AND THE CARBON CYCLE OF LAKES

Åberg and Rodhe defined in 1942 TROPHY in the following way:

"Trophy of a lake refers to the **rate** of organic matter supplied by or to the lake per unit of time. Trophy is an expression of the combined effects of organic matter, supplied to the lake from autrophic production and from allochthonous sources."

This definition became the starting point, after introduction of the ^{14}C-method (Steemann-Nielsen, 1952), for the modern concepts of oligotrophy and eutrophy. "The grouping of lakes may be seen as spectrum of states of lake metabolism between the extremes of oligotrophy and eutrophy" (Wetzel, 1983).

But even if we could measure both sides of organic supply - autotrophic production and allotrophic (or allochthonous) sources - we would not comprehend the lake as an ecosystem. Production and decomposition belong to the metabolism of an ecosystem. Autotrophic production and heterotrophic decomposition are equivalent compartments and are characterized by a metabolic coupling. In the "heterotrophic succession" of the community metabolism bacteria play a dominating role.

Our knowledge of the role of bacteria is almist always qualitative, not quantitative. The mineralization in eutrophic lakes with predominant participation of bacteria are considerable: **more than 80% of the primary production is decomposed in the upper 5 metres of the lake. Only about 20%, in many cases much less, is sinking down to the sediment surface.**

2.13 METABOLIC COUPLING PHYTOPLANKTON - BACTERIA

A metabolic coupling of autotrophic and heterotrophic processes could be concluded also from the distribution pattern of phytoplankton and bacteria. In the vertical profile of stratified eutrophic lakes a clear correspondence of phytoplankton and bacteria is obvious: the maxima are in the same depth (Overbeck & Babenzien, 1964).

It is essential for the understanding the food web, that the correspondence between algae and bacteria is not only **quantitative**, but also **qualitative**: Together with successions of phytoplankton corresponding successions of the bacterial populations are observed. In Lake Plußsee distinct spring-, summer- and autumn-populations of aquatic bacteriaare the result of a metabolic coupling between phytoplankton and accompanying bacteria (Moaledj, 1980; Witzel, Overbeck & Moaledj, 1982).

About 40% of the primary production are channelled immediately through the bacterial metabolism in an annual range. This demonstrates the important role of bacteria in the carbon cycle: extracellular dissolved organic matter (DOM), produced by the autotrophic algae, is converted by bacteria into particulate organic matter (POM), which thus again is available for the food chain.

Fig. 2.3 gives a general scheme of the dominance of heterotrophic bacteria in the transformation of dissolved organic compounds (DOC). Without knowing the dimensions of this "bacterial bypass" (Overbeck, 1972) or "microbial loop" (Fenchel, 1987) the aquatic ecosystem cannot be understood fully.

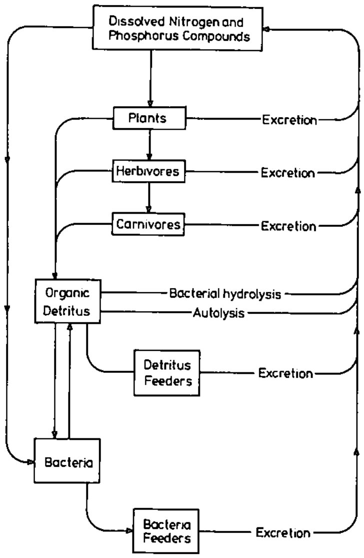


Figure 2.3 Exchange and regeneration of phosphorus and nitrogen in aquatic ecosystems (from Johannes, 1968).

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CHAPTER 3

PROBLEMS OF LAKES AND RESERVOIRS

3.1 OVERVIEW

Problems of lakes and reservoirs are caused by the anthropogenic use of these ecosystems. Most lakes have multiple uses and the problems are related to the conflict between these uses, for instance a lake is used for discharge of waste water and as well as recreational area. The solutions to the problems obviously must take into consideration *all* the uses and attempt to *solve* the conflicts between them. It is hardly possible to find the optimum solution to each of the lake uses, but it is necessary in practical lake management to find a compromise between two or more uses, which of course render the management problem more complex. Many lakes are, for instance, used for production of drinking water as well as for discharge of waste water. The conflict between these two uses is obvious.

Modelling is a particularly useful tool in lake management, see also chapter 6, because a model is able to synthesize the knowledge of the system and the problems.

Lakes and Reservoirs are utilized by man for:

1) Production of drinking water
2) Production of electricity
3) Recreation
4) Fishery
5) Aquaculture
5) Discharge of waste water

Information on the cause of a lake problem is needed to be able to find a solution to the problem. Here the application of mass balances, see chapter 5, is very important to reveal the source.

The sources or causes of lake problems may be summarized as follows:

1. **Discharge of organic biodegradable wastes.**
2. **Discharge of nutrients from waste water.**
3. **Non-point pollution of nutrients, mainly coming from agriculture.**
4. **Acid rain (caused by air pollutants : SO_2 and NO_x)**
5. **Discharge of toxic substances from industries or agriculture.**
6. **Thermal discharges.**

3.2 RELATION BETWEEN PROBLEM AND CAUSE

The basis of a sound lake management strategy is a clear definition of the problem(s) and its (their) cause(s). Table 3.1 attemps to set up a problem/cause matrix to survey the relationship between the environmental problems and their sources. The selection of remedial techniques is, see also chapter 7, closely related to the sources. It is therefore a substantial part of the management strategy to reveal in details all the sources. The problem often may be caused by more than one source, as illustrated by the pollution tetrahedron in Figure 3.1.

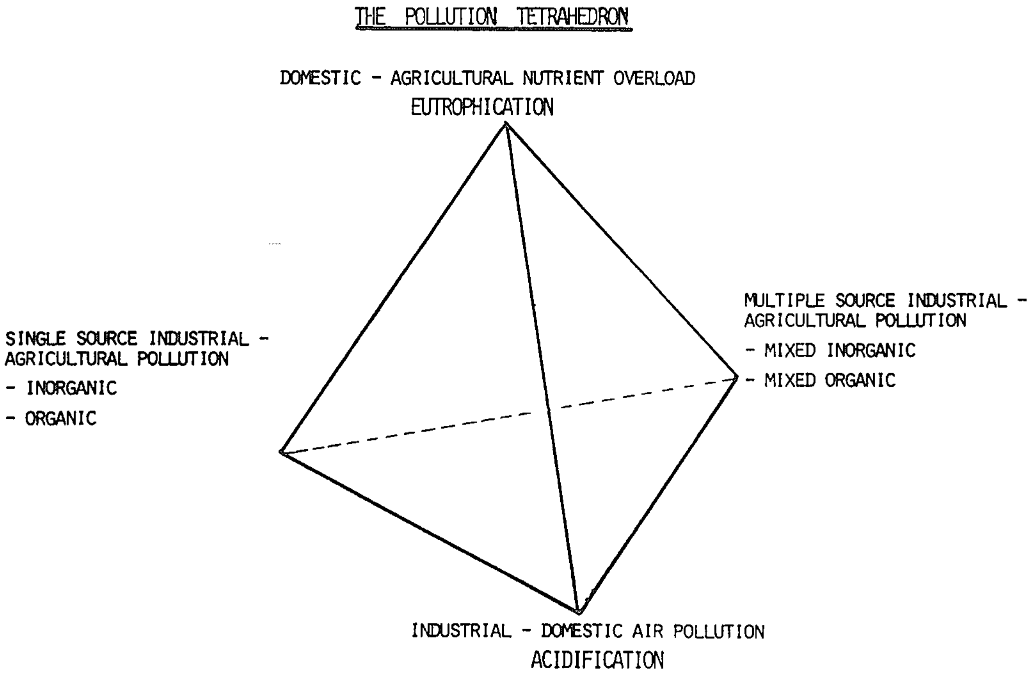

Figure 3.1 Pollution tetrahedron.

Lakes have buffer capacities, it means that they are able to resist a certain level of pollutants. However, the buffer capacities are limited and the outbreak of a problem may therefore occur during a relatively short period of time, while the input of pollutants to the lake has lasted for a considerable longer period, see Figure 3.2. The ability of sediment to accumulate pollutants may often explain this buffer capacity. At a certain level of accumulation the capacity of the sediment has been exhausted and further input of pollutants will increase the concentration in the water phase significantly. If the condition of a lake is not followed carefully, it may therefore look like the problems emerge suddenly, but the cause of the entire complex of problems may have started several years ago. Consequently, it is of significant importance to perceive a lake problem at the earliest possible stage. It is much easier to solve the problem, when it is possible in the mangement strategy to take advantage of a certain buffer capacity than when the buffer capacity has been exhausted.

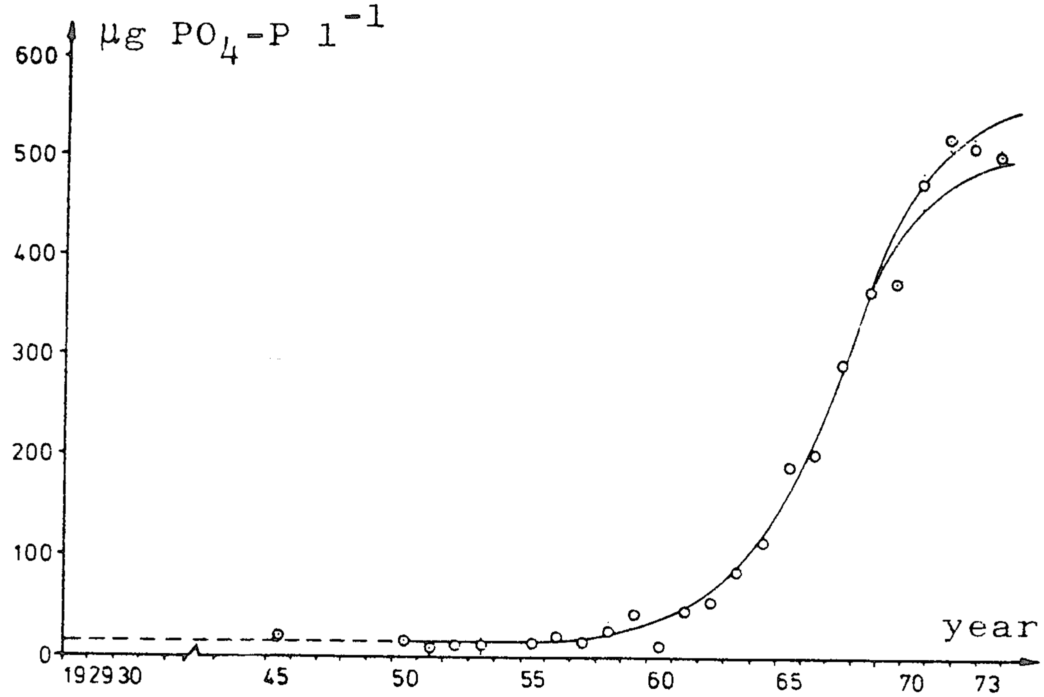

Figure 3.2 Phosphorus concentration in Lake Fure versus time. The phosphorus loading has increased linearly during the period.

Considerations on lake mangement strategies include therefore application of lake restoration methods - also called ecotechnolgy - to attempt to bring the lake faster back to an "equilibrium of reduced problems". As discussed in chapter 7, more remedial methods must work hand in hand to solve most practical lake management problems. In other words lakes have multiple problems caused by multiple sources and their solutions require use of multiple remedial techniques, see also chapter 7.

The problems listed in Table 3.1. are interactive in the sense that one problem may often give rise to other problems, because a lake is a system, where all the components are linked.

Table 3.1
Problems associated with lakes and reservoirs

Problem areas	Caused by, or indirectly depending on			
	Excessive nutrient discharges leading to		Inorganic and organic waste discharges	Acid rain
	Algal blooms & shifts in species composition	Excessive macrophyte & littoral algal growth		
1. Water Quality Impairment				
- taste & odours, colour, filtration, flocculation, sedimentation and other treatment difficulties	xxx	x	x	-
- hypolimnetic oxygen depletion, PH changes, Fe, Mn, CO_2, CH_4, H_2S	xxx	xx	xx	x
- toxicity	x	x	x	-
- occulusion and corrosion problems in pipes and other man-made structures	xx	x	x	x
2. Recreational Impairment				
- unsightlyness	xx	x	xx	-
- hazard to bathers	-	xx	-	-
- increased health hazards	x	x	x	-
3. Fisheries Impairment				
- fish mortality	xx	x	xx	xx
- undersirable fish stocks	xx	x	-	x
4. Aging and reduced holding capacity and flow	x	xx	-	-

Frequency and/or importance: xxx very high, xx high, x occasional, - not applicable

A development of a complex of problems may occur and can be demonstrated by the following example:

1. Excessive nutrient discharges originated from waste water and agricultural run off lead to algal bloom. The transparancy is reduced causing recreational impairment.
2. Oxygen depletion in hypolimnion due to oxygen consumption by mineralization of detritus originated from the algal biomass. Water quality impairment is recorded.
3. Continous oxygen depletion implies formation of hydrogen sulfide. The results are further recreational and water quality impairment.
4. The formation of hydrogen sulfide causes high fish mortality. Impairment of fishery.

Table 3.1 (continued)
Problems associated with lakes and reservoirs

Problem areas	Caused by, or indirectly depending on		
	Others		
	Turbidity and silting	Low dissolved solids and humic substances	Thermal discharges
1. Water Quality Impairment			
- taste & odours, colour, filtration, flocculation, sedimentation and other treatment difficulties	x	x	-
- hypolimnetic oxygen depletion, PH changes, Fe, Mn, CO_2, CH_4, H_2S	-	x	x
- toxicity	-	-	-
- occulusion and corrosion problems in pipes and other man-made structures	x	x	-
2. Recreational Impairment			
- unsightlyness	x	-	-
- hazard to bathers	-	-	-
- increased health hazards	-	-	x
3. Fisheries Impairment			
- fish mortality	x	-	x
- undersirable fish stocks	-	-	x
4. Aging and reduced holding capacity and flow	x x	-	-

Frequency and/or importance: xxx very high, xx high, x occasional, - not applicable

The four stages described above illustrate a stepwise deterioration of a lake ecosystem. It may even be possible to observe a "run away" effect. If the sediment gets anaerobic the release of phosphorus from the sediment is accelerated, which causes an increased algal bloom, which causes a further oxygen depletion in the hypolimnion and so on.

The conclusion is very clear: recognition of a environmental lake problem at the earliest possible stage followed by application of a sound and consequent environmental mangement strategy not only prevents deterioration of the lake, but renders the environmental management so much easier, cheaper and controllable.

CHAPTER 4

QUALITATIVE AND QUANTITATIVE ASSESSMENT OF THE PROBLEM

4.1 INTRODUCTION

The aim of this chapter is to review the major classification of lakes and how chemical, hydrological and biological studies of lakes can be applied and modfied for assessment of lake typology and classification. While a biological classification is aproved and accepted for running waters (Kolkwitz & Marsson, 1909; Liebmann, 1951, 1960), we are confronted with a high diversity of methods for running waters:

1. **Classification** based on the abiotic and biotic conditions in the lakes,
2. **Models of eutrophication** (or pollution) based on the loading from the catchment area.

The knowledge of structure and function of the limnetic ecosystem (see Chapter 2) is one of the suppositions for the study of lake classsification. Because of the importance of the biogeochemical cycles, especially nutrient cycling, we will again briefly refer to it. Then the basic techniques ("How to do it") in field studies on lake classification will be described.

4.2 NUTRIENT CYCLES: THE PHOSPHORUS CYCLE

For a detailed discussion of the phosphorus cycle, can be refered to textbooks in limnology (e.g. Wetzel, 1983). Only some features which are typical and important for lake classification and typology can be described here.

1. In the epilimnetic open water zone we find the following fractions (Fig 4.1): **particulate phosphorus** contains the bulk of phosphorus. The fraction of **soluble orthophosphate** is very small with an extremely short turnover time (often minutes). From the low molecular weight **organic phosphorus** fraction orthophosphate continously is released, predominantly by the activity of free phosphatases, and then become

available to phytoplankton. The primary production of epilimnetic phytoplankton is based on this fast running cycling pool. Due to their metabolic activity (high degradation rate of particulate phosphorus, exoenzyme activity) bacteria are of major importance for the dynamics of phosphorus cycling in waters.

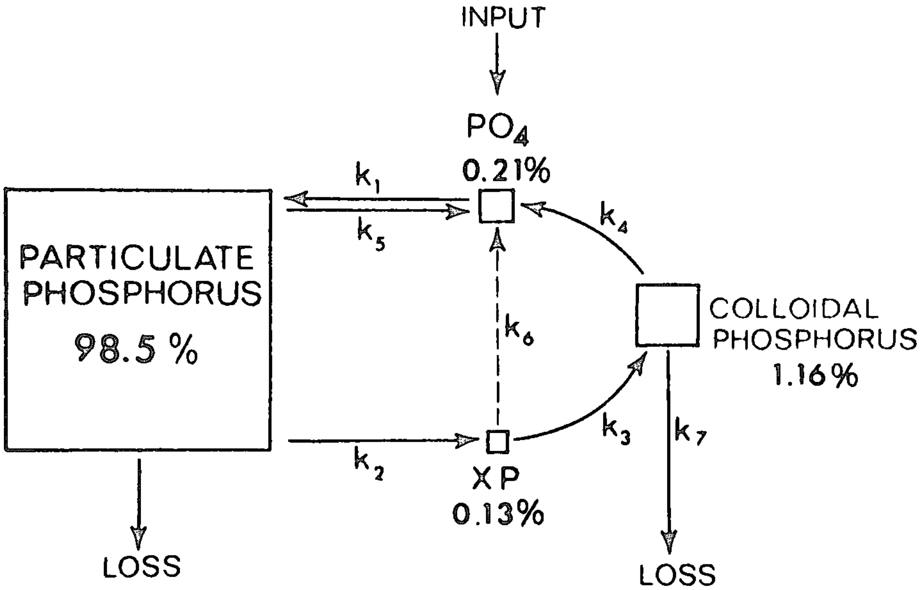

Figure 4.1 Phosphorus movement within the epilimnetic open water zone of lakes, showing the relation between particulate and dissolved phosphorus fractions (from Wetzel, 1983).

2. Fig. 4.2 shows the generalized vertical distribution of soluble (P_s) and total (P_T) phosphorus in stratified lakes of very low (oligotrophic) and high (eutrophic) productivity. During periods of stratification in the eutrophic lake with oxygen depletion in the hypolimnion, a strong increase of dissolved, mostly inorganic phosphorus is found in deeper anoxic parts. Because of the low exchange rate between epilimnetic and hypolimnetic waters this accumulation of phosphorus is not immediately available for the epilimnetic primary production.

High exchange rates across the sediment interface are under anoxic conditions responsible for internal loading of the hypolimnion. The phosphorus cycle is thus strongly connected with the **redox conditions** of the lake: in the epilimnion and after intrusion of oxygen during the autumnal circulation into the deeper anoxic parts of the lake ferrous iron will be oxidized and produces a drastic reduction of dissolved inorganic phosphate partly by adsorption on ferric hydroxide and $CaCO_3$, partly by precipitation of ferric phosphate. An **oxidized** microzone on the sediment surface acts as phosphorus trap preventing a significant release of dissolved phosphate from the interstitial waters of the sediments to the overlaying bottom waters of the lakes. Besides this the phosphorus content of metalimnion and hypolimnion depends on rates of sedimentation of plankton, rates of decomposition and development of microbial populations in the depth of the lakes.

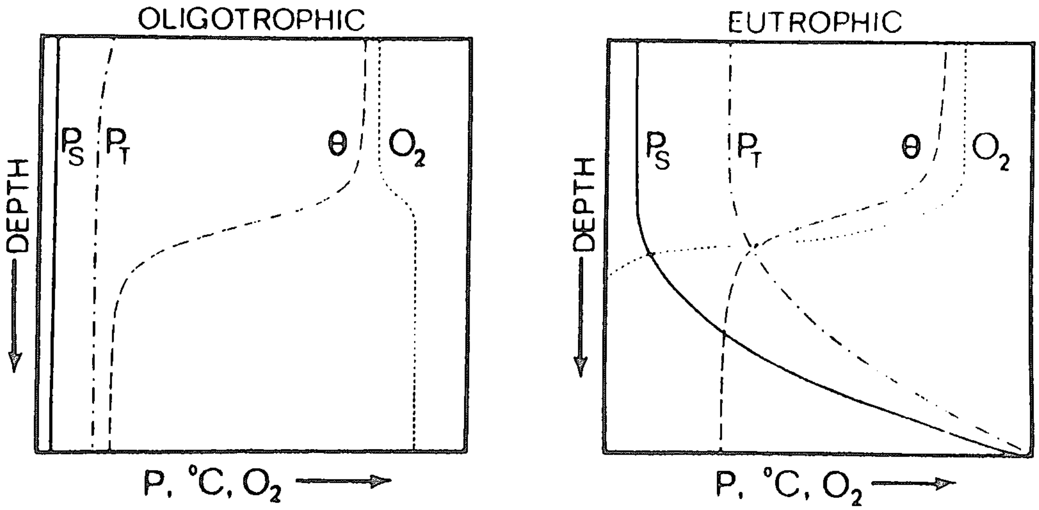

Figure 4.2 Generalized vertical distribution of soluble (P_S) and total (P_T) phosphorus in lakes of very low and high productivity (after Wetzel, 1983).

4.3 THE NITROGEN CYCLE

Dissolved nitrogen compounds include ammonia nitrogen, nitrite, nitrate, dissolved molecular nitrogen and a high diversity of organic compounds (e.g. amino acids, proteins, nucleotides, refractory humic compounds with low nitrogen content). In contrast to the phosphorus cycle, with a very important physico-chemical component, the nitrogen cycle is controlled by microbiolo- gical processes: nitrification, denitrification, fixation of molecular nitrogen, nitrate ammonification. Oxygen has a decisive influence on the whole cycle, determining rates of nitrification or denitrification (occurs only under anoxic or low oxygen condition), etc. Fig. 4.3 summarizes the numerous oxidation and reduction stages of nitrogen compounds. Ammonia is nitrified largely by *Nitrosomonas* to nitrite. Oxidation of nitrite proceeds further to nitrate by *Nitrobacter.* Both bacteria are chemolitotrophic bacteria. Much of the energy released by the oxidation is used for CO_2-fixation via the Ribulosediphosphate-Carboxylase (Rubisco):

Nitrosomonas: $NH_4^+ + 1.5\ O_2$ -- $NO_2 + 2H^+ + H_2O$ ($\Delta G_0'$ - 276 kJ)

Nitrobacter: $NO_2^- + 0.5\ O_2$ -- NO_3^- ($\Delta G_0'$ - 75 kJ)

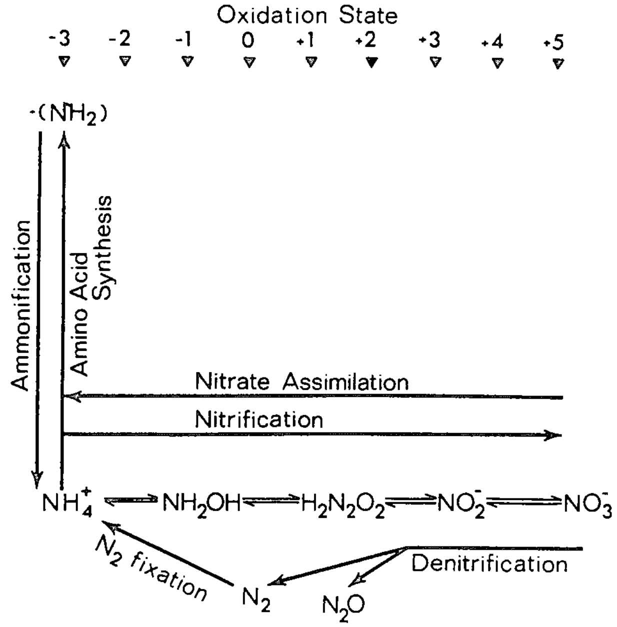

Fig. 4.3: Biochemical reactions influencing the distribution of nitrogen compounds in water (from Wetzel, 1983).

Nitrification means the biological conversion of organic and inorganic nitrogenous compounds from a reduced state to a more oxidized state. In the pelagic zone of the lake the number and activity of nitrifying bacteria is unexpected low. Nitrifying bacteria are originally soil bacteria, their specific field of activity is therefore the sediment.

In contrast again to the phosphorus cycle the loading of a lake with nitrogen compounds from direct terrestrial run-off can be very high: nitrogen compounds have a high mobility and are not absorbed to soil, clay, ferric hydroxide etc., as it is the case with phosphorus. Depending on local meteorological conditions loading of a lake by precipitations can also be very important.

Fig 4.4 summarizes the general vertical distribution of nitrate and ammonia in stratified lakes of high and low productivity. In anoxic hypolimnetic waters ammonia is accumulated due to denitrification of nitrate, release of reduced nitrogen compounds from the sediment, and decomposition (desamination of organic nitrogen compounds). In well-oxygenated waters the concentrations of ammonia are generally low, but depend on the actual state of metabolism. Thus, after a breakdown of phytoplankton populations also in the aerated epilimnion higher amounts of ammonia may be present before nitrification of the reduced nitrogen compounds. Very common is the development of a "nitric plate" in the metalimnion due to nitrification or denitrification of the metabolically extreme activ bacterial populations in this part of the lake.

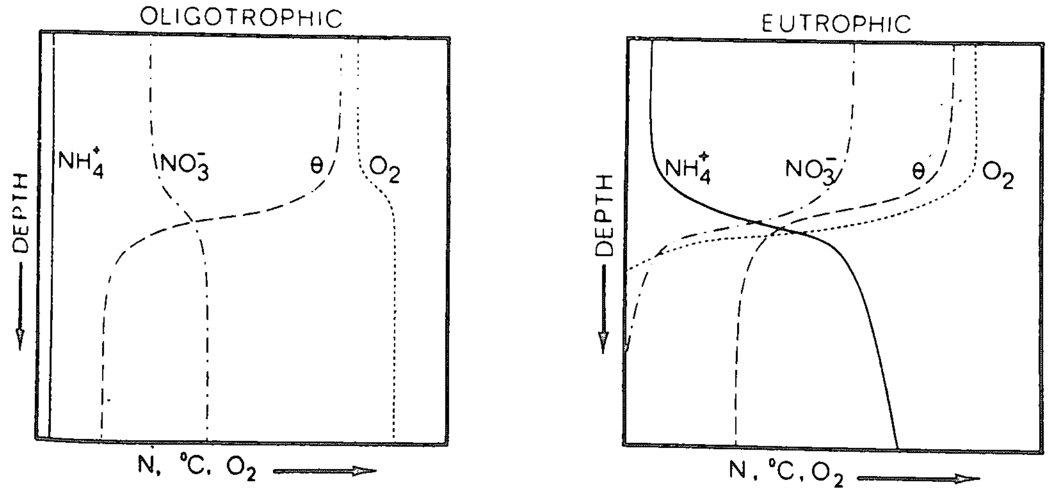

Figure 4.4: Generalized vertical distribution of ammonia and nitrate, nitrogen in stratified lakes of very low and high productivity (from Wetzel, 1983).

4.4 METHODS FOR TROPHIC STATE QUALIFICATION

The evaluation of the trophic status of a lake, is based upon many data, such as lake basin morphology, physioco-chemical parameters, biological parameters and various rates of lake metabolism. In addition, hydrological parameters are also indispensable.

In the following we will give a comprehensive list of methods and how they can be used to assess the problem. The methods are not given in the text but references on where to find details. It seems reasonable to consider also older methods which are still useful and applicable; although they often are of regional value only.

1. Composition of the phytoplankton community (Nygaard)

Nygaard (1949) determined a quotient of the relation of numbers of species of *Cyanophyta, Chlorococcales, Centric Diatoms* and *Euglenophyta* on the one side and *Desmidiales* on the other side. The quotints can be related to different lake-types in the following way:

oligotrophic	fresh waters:	< 1
eutrophic	fresh waters:	1 - 5
polytrophic	fresh waters:	> 20

2. Protein content of water (Ohle)

Ohle (1955) applied protein as measure of biomass and combined it with Nygaard's phytoplankton quotient:

Trophic state	Time	µg protein / l
oligotrophic	year	< 300
low eutrophic	< 1 month	> 300
medium eutrophic	several months	> 500
strongly eutrophic	year	> 500

3. Correlation between total phosphorus and chlorophyll A (Dillon an Rigler)

Regarding the fact that eutorphication of lakes is connected with an increased biomass Dillon and Rigler (1974a and b) evaluated a correlation between total phosphorus and chlorophyll A. Precondition for a good correlation and probability of prediction is a N:P ratio > 12, i.e. phosphorus must be the potential limiting factor. The regression with a correlation-quotient of $r = 0.95$ is as follows:

$$1g\ (chl\ A) = 1.499\ lg\ P - 1.136$$

Sakamoto (1966) published a similar relation for japanese lakes.

The chlorophyll A content, i.e. the development of phytoplankton during summer months can thus be predicted from the phosphorus content in the lake during spring overturn, that is in temperate lakes immediately after icebreak before development of the spring bloom.

From the predicted biomass (chlorophyll A) the tolerable phosphorus content of the lake can be estimated.

The correlation can be combined with the nutrient loading model (Vollenweider, 1979) predicting the phosphorus content during spring overturn from the phosphorus loading (see also Chapter 6).

For similar approaches see also Shapiro (1979), Forsberg and Ryding (1980).

4. Multivariate Trophic State Index (Carlson)

Carlson's (1977) Trophic State Index is based on the following studies:

Prediction of phosphorus concentration in lakes from loading data (Vollenweider 1969, 1976, 1979; Kirchner and Dillon 1975),

Correlation of total phosphorus/chlorophyll A (Sakamoto 1966, Dillon & Rigler 1974),

Prediction of the hypolimnetic oxygen deficit from Secchi disk measurements (Lasenby 1975).

From correlations between Secchi disk readings, chlorophyll A and total phosphorus, equations are derived for the determination of Trophic State Index (TSI). Secchi disk readings are the key parameters of TSI.

The application of such index is rather problematic. For example the biomass of phytoplankton (chlorophyll A) can be controlled by the grazing pressure of the zooplankton, resulting in a smaller biomass than predicted from the equations. On the other hand an increase of the phytoplankton biomass beyond the predicted values may be due to a short circuit phosphor metabolism.

Modifications of the TSI of Carlson from Porcella, Peterson and Larsen (1979) (LEI - Lake Evaluation Index) and Osgood (1982).

5. Quantitative assessment (Schröder and Schröder)

The Schröder's (1978) model is based on two different groups of parameters, which are indicative for production and decomposition:

Production (P)

Annual average concentration of total phosphorus in the euphotic zone (0-10 m)

Annual average temperature of this zone quotient from radiation of one year divided by a longterm medium value of radiation.

Mean depth (z).

Decomposition (R)

Annual average concentration of ammonia as % of total inorganic nitrogen in the whole water column.

Annual average temperature above sediment in °C.

Area of the lake in km^2.

The P:R ratio included in the Schröder-model is an excellent functional index of the relative maturity of a system. If the P:R ratio approaches 1, production and decomposition are balanced as it is the case in the mature or "climax" ecosystem (Odum, 1971). If the P:R ratio is less than 1, decomposition exceeds production. In the opposite case (P:R > 1) production exceeds decomposition. In both cases appropriate remedial techniques are needed to balance the system.

6. Lake metabolism as index of trophic state of a lake

By measurement of the primary production with ^{14}C-bicarbonate (Steemann-Nielsen, 1952) and the heterotrophic microbial activity by means of the heterotrophic potential using ^{14}C labelled organic substrates (Wright and Hobbie, 1966) production and decomposition can directly be measured. There is a good correlation between pelagic autotrophic production and decomposition rate of bacterial populations. The bacteria are extremely adapted to the trophic state of the lake. Therefore, a Trophic State Index can be measured rather simple and fast (20 min) from uptake rates of bacteria (Overbeck, 1973). As an average in eutrophic lakes with a production of 500-1000 mg C m^{-2} d^{-1}, the heterotrophic potential amounts 1 µg C l^{-1} h^{-1}; in oligotrophic lakes 0.1 µg C.

The ^{14}C-labeled organic substrates which are commonly used for measuremen of a heterotrophic potential are glucose, acetate or aminoacids. By application of different concentrations the determination of uptake kinetics in situ is possible: from the max. uptake rate and the K_m-value we get informations on the physiological state of bacteria and phytoplankton.

Application of one dissolved organic substrate for measurement of heterotrophic activity does not comprise the total microbial production.

Fuhrmann and Azam (1982) introduced the incorporation of thymidine as a measure of total heterotrophic bacterioplankton production. This method is now widely used and gives adequate correct values for comparing the bacterial production with the autrotrophic site of the ecosystem.

A comprehensive introduction into field and laboratory methods offer Limnological Analysis by Wetzel and Likens (1979). The book is highly recommended.

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CHAPTER 5

ASSESSMENT OF MASS BALANCE

5.1 INTRODUCTION

The basis of any theoretical and practical consideration pertinent to lake management is the establishment of a sound mass balance. This applies to both water as a solvent, and the solutes themselves. This implies knowledge of what arrives to a lake from its catchment basin, and the sizes, distribution and release pattern of and from these sources (see also chapters 1-2). In regard to the processes in the lake, this reduces to an input-output (black box) model. Inputs to the lake are all quantities which arrive to the lake from outside, either by direct or by indirect discharges. The outputs are the sinks which can be the losses through the outlets, the losses to the sediments, or the losses to the atmosphere. In this context, a source which requires special consideration is the sediment itself, which is not only a sink for material but, under certain conditions, can also act as an internal source.

According to this preamble, the practical approaches to the mass balance question entails two main subjects:

(a) the evaluation of the water balance, and
(b) the evaluation of the balance of any substance in question (e.g. phosphorus, nitrogen, etc.)

As far as possible, these evaluations should be based on measurements in both areas, the catchment system, and the lake. If direct measurements are not available, or impracticable for some reason, indirect estimates may be made; however, indirect estimates must be used and interpreted with caution.

5.2 THE WATER BALANCE

The establishment of a sound water balance may be more intricate than it appears. There are several basic measurements which are absolutely necessary:

The morphometry and volume of the lake

The morphometry of a lake is done measuring the depth contours of an appropriate number of lateral and longitudinal transects from which a bathymetric map is drawn. By planimetry of consecutive isolines, hypsographic curves of the area and volume against depth can be constructed. Such hypsographic curves serve a number of purposes as will be shown later on

Care must be taken for lakes of complex morphometry. Basins of multi-basin systems should be treated separately.

River discharge

The hydrological load or water discharge of the main tributaries should be measured on gauged river stations of known transect. It is important that such measurements are carried out continuously to catch high water load situations. As will be discussed later, hydraulic load peaks often coincide with high nutrient loads which, using only intermittent measurements, are easily missed.

The hydraulic load of less important tributaries could often be approximated by extrapolation from the knowledge of the discharge pattern of the main tributaries, and the established rain pattern. To this end, appropriate deflux values are used. The deflux value(s) is defined as:

$$Q_r / R_r \qquad (5.1)$$

where

Q_r = hydraulic load of a river or rivers measured at gauging station(s) over a certain period, which should be at least one year, and

R_r = total rainfall in the corresponding river basin(s) over the same period of time.

From this, then, the contribution of smaller tributary basins can be estimated as the product of rainfall adn r.

The appropriate values of R_r are normally obtained from the meteorological service. However, approximate long-term estimates from climatological maps and plainmetry of the tributary basins could also be used.

Though hydrological measurements are available from the hydrological service in most countries, the resolution necessary for single lake cases is not always sufficient even in countries of advanced hydrological monitoring.

It is therefore important to assess the available information in the light of the particular need for specific mass balance studies. Also, distinction has to be made between the hydrological regime of a particular year (e.g. the year, or years of intensive studies) and the long-term average hydrological regime. The latter serves as reference to assess the particular situation of selected individual years.

Data processing and presentation may be made in various ways. It is customary to plot the **instantaneous discharge** (discharge in m^3/day) against time, and to calculate the average discharge rate per year. Another useful representation is plotting **discharge height duration** progressively from day 0 to day 365. Discharge-duration diagrammes are particularly useful for comparative studies either in time (sequence of year against long-term means) or for comparisons of the prevailing hydrological regime of different lakes. Also, discharge height duration diagrammes give immediate indication of the probability of occurrence and frequency of high water loads, and hence, of the meaning and appropriateness of calculated yearly mean values.

Complete water balance

The above factors form the basic information needed to establish a water mass balance, but still they are insufficient. A complete water balance requires that

$$Q + R - O - E = \frac{\Delta V}{\Delta t} \ (m^3/t) \qquad (5.2)$$

where
Q = total hydrologic load from tributaries over time Δt
R = direct rainfall on lake over the same time period
O = loss through outlet(s) during Δt
E = evaporation from lake surface during Δt
$\Delta V/\Delta t$ = volume change (positive or negative) of lake

Q, R, O and $\Delta V/\Delta t$ can, with the appropriate precaution, normally be estimated reasonably well. Evaporation is more difficult to measure. If important, E can be estimated from the other terms. Evaporation becomes important in arid and semi-arid climates, while in temperate regions E and R are often of comparable magnitude. The term $\Delta V/\Delta t$ is of particular importance in highly fluctuating reservoirs.

The variability in (R-E) and $\Delta V/\Delta t$ creates a number of problems for generalization. However, under conditions of relatively steady state, some usefull, though theoretical, terms can be calculated, such as

$$q = \frac{Q}{A}, \text{ the hydraulic load per unit lake surface area (A) } \left(\frac{m^3/y}{m^2} = \frac{m}{y}\right);$$

$$T(w) = \frac{V}{Q}, \text{ the theoretical filling time of the lake } \left(\frac{m^3}{m^3/y} = y\right);$$

or its reverse

$$r(w) = \frac{Q}{V}, \text{ the average flushing rate (l/y).}$$

If the terms (R-E) and $\Delta V/\Delta t$ cannot be neglected, the above values are still valid but, for comparative studies, the corresponding terms, replacing Q by O, may be more useful. Nevertheless, it is not always a satisfactory solution. Therefore, appropriate judgement by the investigator is necessary.

5.3 SUBSTANCE BALANCE

The establishment of the balance of any substances (e.g. phosphorus, nitrogen, mineral turbidity, etc.) is closely connected to the water balance though not identical to it. Solutes are normally measured as concentrations (e.g. g/m^3); however, certain substances like nitrogen, carbon a.o. may also have a gaseous phase; accordingly, their pathways have to be determined differently. In the context of the following, this problem shall not be pursued to any degree necessary. Readers will have to consult special treatises.

The most important step in drawing up a substance balance sheet entails a precise estimation of the total load to a given body of water. In this case, a direct measurement is preferable to an indirect estimate. However, as direct measurements are not always entirely possible, techniques for indirect estimates will also be discussed.

The load of any one substance to a lake is a function of the various sources located in the basin, of their size, loss coefficient and specific pathway. Basically, sources can be classified as either point sources or non-point sources (diffused sources) (see also chapter 1-2). Conceptually, this distinction is useful though, operationally, certain problems may arise at times for an unequivocal definition. As regards the main pathways, point sources may be either direct sources (e.g. direct discharges into a lake through discharge pipes) or indirect, i.e. upstream discharges into a main or lateral tributary. To some extent this distinction can also be applied to diffused sources.

Inventory of point and non-point sources

As regards lake management, which frequently is a matter of managing the sources, the most important basic work entails a complete assessment of all the sources of the substance in question, i.e. a source inventory. Such an inventory should list type, strength and location of all the direct and indirect point sources separately, and all the diffused sources and their areal distribution. This information could be presented in tables and appropriate source maps.

Direct point sources are normally discharge pipes from urban and industrial complexes and, at times. from agricultural operations (e.g. stable and feed-lot discharges). In general, the inventory of such sources does not create unmanageable problems. For urban sources, population figures should be given, and be listed according to how they are served by sewer systems. Special attention should be given to areas and situations of massive tourist influxes.

Diffused sources, on the other hand, are more difficult to come by. Such sources are: agricultural areas (arable land and its utilization (crops, orchards, pastures), forest areas, unproductive areas, urban and transportation areas (streets and highways), etc. Beside the generic, i.e. percent areal breakdown, of the basin according to such land use categories, this information should be supplemented with e.g. amount and kind of fertilizers and/or pesticides used, number and kind of animals (cattle, hogs, poultry, etc.) per area, as well as any information which is pertinent to the question (e.g. number of cars, dumping sites, etc.). It should be noted that, in regions where sewer systems do not exist, the waste-water discharge from individual households has to be treated as a non-point source. Important for non-western countries!

This information is important for the design and the optimization of a direct measurement programme, and serves also for indirect load estimates.

Load estimates by direct measurements

A direct measurement programme requires the selection of an appropriate sampling station network whereby the stations are to be located in strategically critical points. Primary points of this sort are locations of pipe discharges, and river stations where water flow is measured (cf. A). Other strategically critical points are locations which serve to evaluate base-line conributions from natural and diffuse sources. If continuous water flow stations are lacking, then at least reasonable spot estimates of water discharge should be made. **In no case should concentrations be reported without direct or indirect estimates of water discharge.** Correct measurement of concentration, of course, is a matter of appropriate sample treatment (e.g. fixation, freezing and other preservation techniques prior to laboratory analysis) and appropriate chemcal-analytical techniques.

Load calculations

In most events, continuous analytical measurement is not practicable. Exceptions may be temperature, conductivity, pH, a.o. if appropriate instrumentation is available. Instrumentation also exists which permits flow-proportional sample integration over limit time periods. Often, however, such equipment is not available. Therefore, load estimates have to be calculated from the relationship between intermittent concentration and concomitant water flow measurements, and continuous water discharge measurements. Calculations have to be made separately for each subbasin of the catchment system.

There are several procedures and considerations pertinent to a correct calculation of the total load.

1. In normal practice total load calculation over time is based on using mean values of concentration and flow, i.e.

$$\text{Load (kg/time)} = \bar{c} * Q_d * \Delta t \qquad (5.3)$$

where

$\bar{c}$ (g/m^3) = meanconcentration of a substance in river water, based on periodical (e.g. daily) observations over a certain period of time (e.g. 365 days)

Q_d = rate of river water discharge observed simultaneously with the concentration

Δt = interval (days) between the observations.

While this procedure may provide a first approximation, and is reasonably correct for sites of relatively constant flow and concentration, in most cases the estimates based on this procedure may be rather questionable.

2. A more correct way to estimate loads requires first to establish the relationship between concentration and the water discharge at the time of measurements by plotting concentration against discharge, and calculating least-square regression equations. This relationship is often not linear. The following cases have to be evaluated as a minimum. If none are satisfactory, others may also have to be explored.

(a) Concentration is independent of flow, and rather constant, i.e.

$$c = K \ (\pm SD)$$

Accordingly, the load for any one day l_d will be proportional to the water discharge, i.e.

$$l_d = \bar{c}\, Q_d \quad \text{(kg/day)} \qquad (5.4)$$

(b) Concentration is inversely proportional to the water discharge, i.e.

$$\bar{c} = \frac{K_o}{Q_d}$$

Accordingly, the load for any one day is:

$$l_d = \bar{c}\, Q_d = K_o \quad \text{(kg/day)} \qquad (5.5)$$

(c) Concentration is proportional to the water discharge, i.e.

$$\bar{c} = K_1 Q_d$$

from which follows

$$l_d = K_1 \ Q_d^2 \quad \text{(kg/day)} \qquad (5.6)$$

A more general expression may result in an exponent different from 2.

(d) In a real situation, however, the more likely relationship will be a combination of all three cases, i.e.

$$\bar{c} = K_o + \frac{K_1}{Q_d} + K_2 Q_d^b$$

and therefore,

$$l_d = K_oQ + K_1 + K_2Q_d^{b+1} \quad \text{(kg/day)} \tag{5.7}$$

At this ground, then, the yearly total load from any subbasin can be calculated from continuous flow measurements, i.e.

$$\text{Load/year} = l_y = \sum^{365} K_oQ_d + \sum^{365} K_1 + \sum^{365} K_2Q_d^{b+1}$$

$$= K_oQ_y + 365K_1 + K_2 \sum^{365} Q_d^{b+1} \quad \text{(g/y)} \tag{5.8}$$

where Q_y is the annual water discharge.

For many practical applications, K_oQ_y can be neglected. If $b \mp 1$, the third term collapses with the first term, and it may be necessary to retain it. Conversely if b is large, the third term may become the overriding one. This has to be judged from the data themselves.

Needless to add that the total load to the lake will be the sum of all the loads from the various tributary subbasins plus what is directly discharged to the lake. In certain cases, the direct atmospheric load must be included also.

Export coefficient and indirect estimates

The export coefficient from any subbasin having an area of D is defined as the load per unit of drainage basin, i.e.

$$ø = \frac{l_y \text{ (g/yr)}}{D \text{ (m}^2\text{)}} = \frac{g}{m^2 \text{ yr}} \tag{5.9}$$

ø may refer to the base load from natural sources (forest, barren land, etc.) or include also anthropogenic sources, too. For comparative studies, such export coefficients are useful, but indirect estimates must be used with the utmost caution. This becomes evident, redefining the equations given above in terms of export coefficient. Accordingly, the export coefficient for a given basin would be

$$I_y / D = \frac{K_o Q_y}{D} + \frac{365 K_1}{D} + \frac{K_2}{D} \sum^{365} Q_d^{b+1} \qquad (5.10)$$

In this equation, the only term independent of the water load is the second one, and which also dimensionally fulfills the criterian of a true export coefficient. While the first term can be neglected in many cases, it is evident that the third term may have strong bearings on the total if the water load regimes in, otherwise similar basins differ markedly. Moreover, this term is the one likely to be responsible for the year to year variations of ø observed in the one and same basin, though the overall conditions within the basin may remain invariant.

Despite such uncertainties, it is possible to make indirect load estimates from, say, land use characteristics, population density, known animal husbandry, industrial sources, etc, see also chapter 6, section 7. Experience has also shown that it is advisable to backcheck load estimates from direct measurements, particularly in cases when no continuous flow measurements are available. If the two load estimates differ by, say, more than 50%, caution has to be applied in using such values.

Estimate of content in the lake

The mass balance equation requires a knowledge of the content of a substance in the lake, and its temporal variation. The basic approaches for this are measurements of concentration at various depths and at different times of the year. A recipe which applies to all situations cannot be given, but general limnology has developed a number of basic rules. The most important conditions to be known are the temporal and spacial variations of temperature at the basis of which the mixing characteristics are defined. These depend primarily on climatological conditions while the more specific characteristics are influenced by lake morpometry, flow regime, weather conditions, ice coverage and, in certain cases, also by salinity and turbidity.

Temperate lakes show typically periods of deep mixing (fall-winter-early spring) and summer periods of thermal stratification. In northern lakes, winter stratification (ice coverage) occurs, while subtropical and tropical warm water lakes may have more mixing-stagnation periods during the year. However, also in these situations, climatic conditions define the more specific mixing characteristics.

A particular class of lakes are oligomictic (no full mixing each year) or meromictic (only partial mixing all the time). See also chapter 2.

The sampling programme has to be tuned to the specific mixing regime (see chapter 2 and appendix 1). As a general rule, during stratification one to two samples should be taken at depth above the thermocline, one or two in the thermocline, and one or more at various depths below the thermocline, depending on the maximum depth. The absolute minimum number of surveys per year should be four, and be adequately spaced in time. Larger lakes require also assessment of horizontal differentiations. Subbasins and lakes of complex morphology need specific investigation. In all cases, one station should be located near, or immediately below the outlet.

Calculation of the content must be volume-based. For this, the depth-water volume curves are necessary. The interpolated mean concentrations (C_z) representing a certain depth stratum is then multiplied by the respective stratum volume, v_z, and the products are summed, i.e.

$$\text{Lake content} = \Sigma \quad c_z * v_z \qquad (5.11)$$

The summation is made from lake surface to the maximum depth (z_{max}).

The volume v_z | is estimated from the depth- volume curve bydifference of the volumes read at the depths corresponding to the upper and lower ends of the stratum.

For cases where no hypsographic curves are available but total volume and mean and maximum depth are known from literature gives approximate volumes between the two depths Z_1 and Z_2 can be estimated from

$$v_z = V \; [(1 - Z_2 / Z_{max})^E - (1 - Z_1 / Z_{max})^E] \qquad (5.12)$$

V = total lake volume

$E = Z_{max} / Z$ where $Z = (Z_1 + Z_2) / Z$

However, this formula should not be applied to lakes of unusual morphometry.

Outflow values are estimated from mean outflow concentration, (c_w) and water outflow rate (Q_w).

$$\text{Outflow losses} = c_w * Q_w \qquad (5.13)$$

In general, average outflow and concentration values give reliable estimates, particularly during periods of deep mixing. It is advisbale to treat summer stagnation situations separately.

5.4 COMPLETE MASS BALANCE

Once the basic information is available, a mass balance for the whole lake can be set up, i.e.

$$L - O \pm \Delta St = (\pm) S \qquad (5.14)$$

Total load - outflow $\neq$ storage change
= (positive or negative) sedimentation

The essential difference between this and the water mass balance equation is, briefly, that sedimentation losses, or (if negative) internal load is estimated.

Yet, this applies only to substances which have no gas phase, e.g. phosphorus. As regards of nitrogen, the interpretation of the residual difference term is more complex. Positive losses may be due to sedimentation as well as to the balance of nitrification-denitrification. Negative values can be the result of internal loading and the nitrification- denitrification balance.

The magnitude of the nitrification-denitrification balance can be estimated approximately from comparison between e.g. the phosphorus sedimentation and the N/P ratio of the load, the in-lake ratio and the sediment N/P ratio. These estimates are not perfect but give at least a clue of the magnitude of the processes. The procedure will be illustrated in more detail later on.

5.5 LOAD ESTIMATE EXAMPLE

Water load and phosphorus load from a river basin

This example refers to a study in the river basin Savio (Northern Italy) conducted by the Emilia-Romagna study group on eutrophication. Figure 5.1

summarizes the discharge duration in m^3/sec (1), the cumulative water discharge in $10^6 m^3$ (2), and the cumulative phosphorus load in t (3).

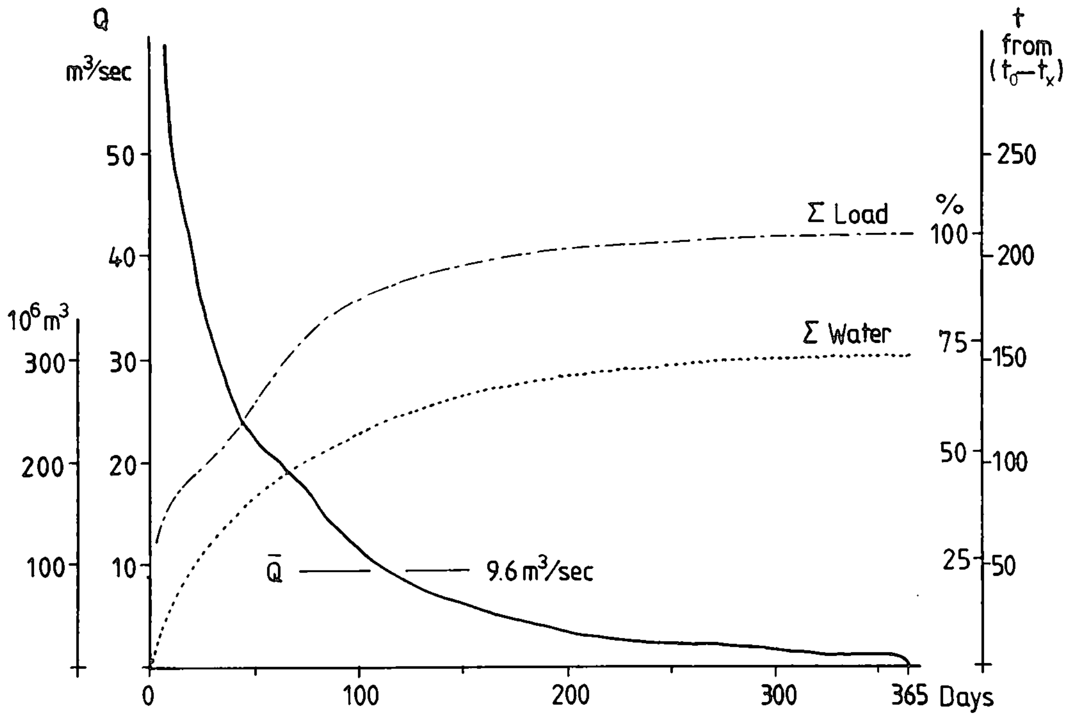

Figure 5.1 River Savio: Phosphorus load and water discharge.

From this the following conclusions can be made:

(a) the yearly mean water discharge, Q = 9.6 m^3/sec is exceeded over a period of 115 days with peak values exceeding 55 m^3/day over 10 days;

(b) during the 115 days, the cumulative water discharge is 240 * 10^6 m^3, Corresponding to 79% of the total yearly water discharge;

(c) during the same period of time, the cumulative phosphorus load from this basin is 185 t, corresponding to 88% of the total yearly phosphorus load.

Further, the following considerations are of interest:

(a) If concentration measurements had been made only during low discharge periods (250 days), their mean values would have been in the order of 0.410 gP/m^3. If this mean value furthermore had been multiplied by the mean water discharge for the whole year, the total yearly phosphorus load would have been estimated to 124 t/year, i.e. substantially lower than the actual load.

(b) Only the other hand, if measurements were taken only during high discharge periods, their mean value would have been in the order of 0.770 gP/m^3. Multiplied by the mean discharge over the whole year, the total phosphorus load estimate would have been 227 t. Contrary to the above estimate, this estimate remains within the uncertainty of the real phosphorus load estimate.

This example should demonstrate the importance of designing the sampling programme correctly, including high discharge periods. In the above example, the measurements covered several high and low discharge periods of the year during which sampling was made every second hour during one week.

Mass balance examples

The following examples are based on studies of Thomas (1955) of the eutrophic Lake Pfaffikon (Pfaffikersee) in Switzerland. As a of demonstration, Thomas' original data have been slightly reelaborated. Also, the shortcoming that the original values for nitrogen are only for mineral nitrogen ($NO_3 + NO_2 + NH_4$) does not essentially disturb the procedure.

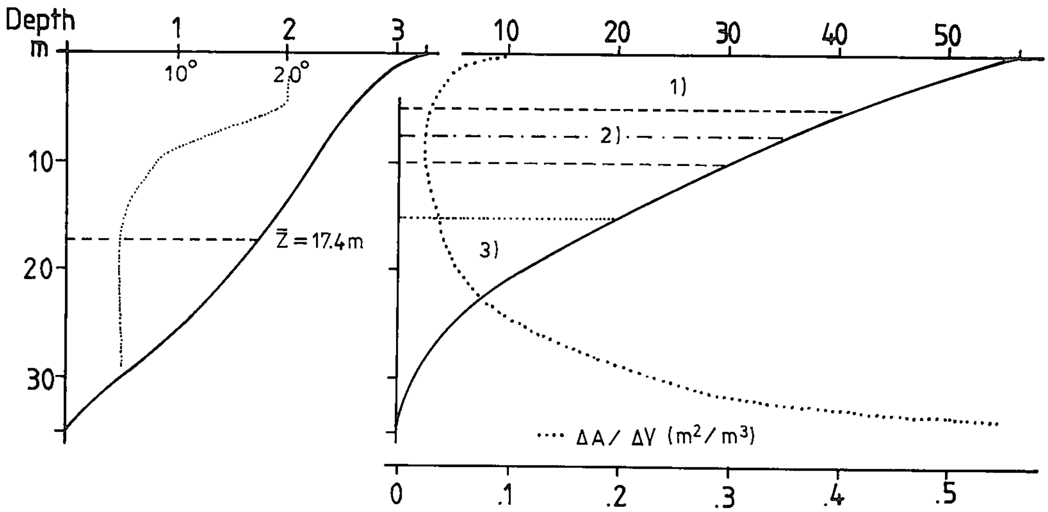

Figure 5.2 Hypsographic curves of Pfäffikersee (Switzerland) 1. Epilimnion: 14.45*10^6 m^3 2. Mesolimnion: 12.1*10^6 m^3 3. Hypolimnion: 29.9*10^6 m^3. A_o = 3.25*10^6 m^2 and V_o = 56.45*10^6 m^3.

The main features of the lake

The essential limnological features of the lake are synthesized in Fig. 5.2 in form of hypsographic curves. In addition to these, the sediment contact ratio

$$\Delta A_s \,/\, \Delta V \quad (m^2/m^3) \tag{5.23}$$

has been plotted. Many of the dynamic characteristics (e.g. oxygen consumption, denitrification activity, nutrient release, etc.) are related to this ratio.

The volume is divided into three compartments (epi, meso, hypolimnion) reflecting the features of thermal stratification during summer. The 0 to 5 m strata are normally well mixed, while the 5 to 15 m strata shows a sharp thermal gradient from 5 to 10 m, and a weaker one from 10 to 15 m. From inspection, the hypolimnion begins at depth of about 12.5 m. For some of the more specific mass balance calculations, such information has to be taken into account. Not all aspects will be explored in the following.

Mass balance for phosphorus and nitrogen from the period of spring mixing to end of summer stagnation

(a) **Whole lake mass balance.** The essential data are listed in Table 5.1.

Table 5.1
Pfaffikersee: Total phosphorus and mineral nitrogen content from 16/2 to 5/10/50 (231 days). Load during the same period: phosphorus: 2720 kg; nitrogen: 30760 kg. Outflow loss: phosphorus: 660 kg; nitrogen: 2470 kg.

Stratum	Volume	Total phosphorus 16.2		Total phosphorus 5.10		Mineral nitrogen 16.2		Mineral nitrogen 5.10	
m	10^6 m^3	mg/m^3	kg	mg/m^3	kg	mg/m^3	kg	mg/m^3	kg
0-5	14.34	65.2	935	9.8	140	625	8962	25	358
5-10	12.22	68.5	837	11.5	140	625	7639	238	2909
10-15	10.26	71.7	736	35.9	368	638	6548	513	5265
15-20	8.42	71.8	604	81.5	686	662	5580	495	3998
20-25	6.32	71.7	453	130.4	824	688	4350	513	3243
25-30	3.71	74.9	278	208.8	775	713	2647	788	2925
30-35	1.18	228.8	270	286.9	338	724	854	1211	1429
0-35	56.45	(72.9)	4115	(58.0)	3271	(648.0)	36850	(356.5)	20127

From this the following mass balance sheets can be set up immediately:

Table 5.2 Mass Balance

	Phosphorus (kg)	Nitrogen (kg)
Lake content 16.2	4113	36580
Load 16.2 to 5.10	+2720	+30760
Outflow loss 16.2 to 5.10	-660	-2470
Net load	(+2060)	(+28290)
Lake content 5.10	-3271	-20127
= Internal losses		
a) phosphorus = sedimentation	2902	
b) nitrogen = sedimentaion + denitrification		44743

In order to estimate the nitrogen loss through processes of denitrification, one can proceed from the assumption that sedimentation of both, phosphorus and nitrogen, is due to sedimentation of biomass. The N/P ratio in healthy biomass ranges between 5 to 10 (5 rather nitrogen, 10 rather phosphorus limited). Accordingly, the nitrogen corresponding to 2900 kg P should be in the order of 14500 to 29000 kg. Hence, denitrification would be in the order of between 30250 (44750 - 14000) to 15750 (44750 - 29000) kg.

However, because of the complex dynamics (e.g. recycling of phosphorus and nitrogen) such estimates are rather vague. A better reference is offered by the sediment N/P ratio. Thomas reports N/P in sediments to 4.9. Accordingly, 2900 kg P equal 14210 kg N. With a total nitrogen loss of 44750 kg, therefore, denitrification is in the range of 30500 kg. Of these, at least some 9000 t occur in the water column (from inspection of the difference between spring and fall content of the 5 to 25 m strata); the rest occurs probably in the sediment.

(b) Mass balance considering epi-hypolimnion fluxes. During the period of summer stagnation, the hypolimnion is more or less isolated from the epilimnion, except for vertical fluxes in both directions. Upward fluxes are possible under conditions of strong concentration gradients (diffusive fluxes and weak advective fluxes), while the main fluxes are downward due to particle sedimentation. While an exact differentiation with simple mass balance calculation cannot be made, one may at least estimate the magnitude of the net fluxes through an arbitrarily defined horizon. For both simplicity and also limnological reasons, let us consider the fluxes through the 5 m horizon. This leads to the following balance sheets:

(1) Phosphorus

(a)	Epilimnion:	
	- content 16.2 (0-5 m)	935 kg
	- load 16.2 - 5.10	+2720 kg
	- outflow loss 16.2 - 5.10	-660 kg
	- content 5.10 (0-5 m)	-140 kg
	Downward flux	2855 kg
(b)	Hypolimnion:	
	- content 16.2 (5-35 m)	3178 kg
	- net flux from epilimnion	+2855 kg
	- content 5.10 (5-35 m)	-3131 kg
	Difference (sedimentation)	2902 kg

Note (i) that this difference is equal (has to be) to the whole lake sedimentation estimate, and (ii) that this is likely an overestimate of the real flux, insofar as probably a slightly higher fraction of phosphorus is sedimented in the 0-5 m littoral zone. Everything equal, this fraction is likely in the order of 10% to 20% of the total.

(2) Nitrogen

(a)	Epilimnion:	
	- content 16.2 (0-5 m)	8962 kg
	- load 16.2 - 5.10	+30760 kg
	- outflow loss 16.2 - 5.10	-2470 kg
	- content 5.10 (0-5 m)	-358 kg
	Downward flux	36894 kg
(b)	Hypolimnion:	
	- content 16.2 (5-35 m)	27618 kg
	- net flux from epilimnion	+36894 kg
	- content 5.10 (5-35 m)	-19769 kg
	Difference (sedimentation + denitrification)	44743 kg

Note that the reasoning made above about phosphorus also applies to nitrogen.

Using the same syllogism, more detailed calculation over shorter time spaces covering the whole year, or several years in a row, can be made. It should be noted that, contrary to the examples considered above, "sedimentation" (particularly for phosphorus) may also be negative. This means that one has to do with periods of internal loading. In eutrophic lakes, this is often the case in situations of prolonged hypolimnetic anoxia. Yet, as the above example shows, this is not a sufficient condition. The oxygen concentration of Pfaffikersee at the height of summer stagnation remains below 0.25 mg/l from 30 m and downwards.

CHAPTER 6

USE OF MODELS

6.1 MODELS AS A MANAGEMENT TOOL

The idea behind the use of ecological management models is demonstrated in Fig. 6.1. Urbanization and technological development has had an increasing impact on the environment. Energy and pollutants are released into ecosystems, where they may cause more rapid growth of algae or bacteria, damage species, or alter the entire ecological structure. Now, an ecosystem is extremely complex, and so it is an overwhelming task to predict the environmental effects that such an emission will have. It is here that the model comes into the picture. With sound ecological knowledge it is possible to extract the features of the ecosystem that are involved in the pollution problem under consideration and to form the basis of the ecological model (see also the discussion in chapter 2). As indicated in Fig. 6.1, the model resulting from this can be used to select the environmental technology best suited for the solution of specific environmental problems, or legislation reducing or eliminating the emission set up.

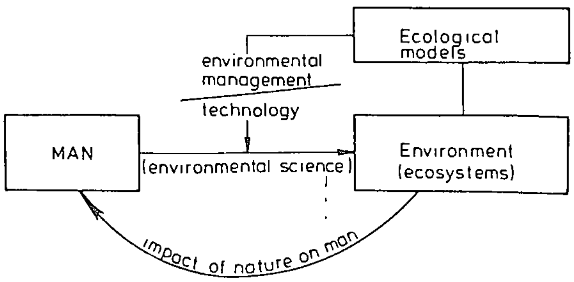

Figure 6.1 Relations between environmental science, ecology, ecological modelling and environmental management and technology.

6.2 ELEMENTS OF MODELLING

An ecological model consists, in its mathematical formulation, of five components:

(1) **Forcing functions or external variables**, which are functions or

variables of an external nature that influence the state of the ecosystem. In a management context the problem to solve can often be reformulated as follows: if certain forcing functions are varied what will be the influence on the state of the ecosystem? The model is, in other words, used to predict what will change in the ecosystem, when forcing functions are varied with the time. Examples of forcing functions are the input of pollutants to the ecosystem, the consumption of fossil fuel, or a fishery policy, but temperature, solar radiation, and precipitation are also forcing functions (which, however, we cannot at present manipulate). Forcing functions, which are controllable by man, are often named **control functions**.

(2) **State variables** describe, as the name indicates, the state of the ecosystem. The selection of the variables is crucial for the model structure, but in most cases the choice is obvious. If, for instance, we want to model the eutrophication of a lake it is natural to include the phytoplankton concentration and the concentration of nutrients. When the model is used in a management context the values of the state variables predicted by changing the forcing functions can be considered as the result of the model, because the model will contain relations between the forcing functions and the state variables. Most models will contain more state variables than are **directly required** for purpose of management, because the relations are so complex that they require the introduction of additional state variables. For instance, it would be sufficient in many eutrophication models to relate the input of one nutrient with the phytoplanton concentration, but as this variable is influenced by more than one nutrient (it is influenced by other nutrient concentrations, temperature, hydrology of the water body, zooplankton concentration, solar radiation, transparency of the water etc.) a eutrophication model will most often contain a number of state variables.

(3) The biological, chemical and physical processes in the ecosystem are represented in the model by means of **mathematical equations**. They are the relations between forcing functions and state variables. The same type of processes can be found in many ecosystems, which implies that the same equations can be used in different models. It is, however, not possible today to have one equation that represents a given process in all ecological contexts. Most of the processes have several mathematical representations, which are *equally* valid either because the process is too complex to be understood in sufficient detail at present, or because some specified circumstances allow us to use simplifications.

It is therefore not surprising that ecological models have been used increasingly in ecology as an instrument to understand the properties of the ecosystem. This application has clearly revealed the advantages of models as a useful tool in lake management; this might be summarized in the following points:

1. Models are useful instruments in **survey** of complex systems.
2. Models can be used to reveal **system properties**.
3. Models reveal **the weakness in our knowledge** and can therefore be used to set up research priorities.
4. Models are useful in tests of **scientific hypotheses**, as the model can simulate ecosystem reactions, which can be compared with observations.

(4) The mathematical representation of processes in the ecosystem contains coefficients or **parameters**. They can be considered constant for specific ecosystem or part of ecosystem.

In the casual models the parameters will have a scientific definition, e.g. the maximum growth rate of phytoplankton. Many parameter values are known within limits. In Jørgensen et al. (1979) can be found a comprehensive collection of ecological parameters. However, only a few parameters are known exactly and so it is necessary to calibrate the others.

By the **calibration** it is attempted to find the best accordance between computed and observed state variables by variation of a number of parameters. The calibration might be carried out by trial and error procedure or by use of software developed to find the parameters that give the best fit.

In many static models, where process rates are given as average values in a given time interval and in many simple models, which contain only a few and well defined or directly measured parameters, calibration is not required. In models aimed at simulating the dynamics of the ecological processes, the calibration is crucial for the quality of the model due to the reasons summarized below:

a. As indicated above the parameters are in most cases known only within limits.
b. Different species of animals and plants have different parameters, which can be found in the literature (see Jørgensen et al. 1979). However, most ecological models do not distinguish between different species of phytoplankton, but consider them as one state variable. In this case it is possible to find limits for the phytoplankton parameters, but as the composition of the phytoplankton varies throughout the year an exact average value cannot be found.
c. The influence of the ecological processes which are of minor importance to the state variables under consideration, and therefore not included in the model, can to a certain extent be considered by the calibration, where the results of the model are compared with the observation, from the ecosystem. This might also explain why the parameters have

different values in the same model when used for different ecosystems. The calibration can, in other words, take the site differences and the ecological processes of minor importance into account, but obviously it is essential to reduce the use of calibration for this purpose. The calibration must never be used to force the model to fit observations if this implies, that unrealistic parameters are obtained. If a reasonable fit cannot be achieved with realistic parameters the entire model should be questioned. It is therefore extremely important to have realistic ranges for all parameters or at least for the most sensitive. This implies that a sensitivity analysis must be carried out, whereby the influence of changes in submodels, parameters or forcing function on the most crucial state variables is found.

(5) Most models will also contain universal constants such as the gas constant, molecular weights etc. Such constants are of course not subject to a calibration.

Models can be defined as formal expressions of the essential elements of a problem in either physical or mathematical terms. The first recognition of the problem is often, and most likely, to be, expressed *verbally* . This can be recognized as an essential preliminary step in the modelling procedure, but the term formal expressions implies that a translation into physical or mathematical terms must take place before we have a model in the sense we are applying throughout this book.

The verbal model is difficult to visualize and it is therefore conveniently translated into a **conceptual diagram**, which contains the state variables, the forcing functions and how these components are interrelated by processes. The conceptual diagram can be considered as amodel, and is named a conceptual model. A number of models in the ecological literature stop at this stage due to lack of knowledge about the mathematical formulation of processes. They can, however, be used to illustrate the relationships qualitatively.

Fig. 6.2 illustrates a conceptual model of the nitrogen cycle in a lake. The state variables are nitrate, ammonium, nitrogen in phytoplankton, nitrogen in zooplankton, nitrogen in fish, nitrogen in sediment and nitrogen in detritus. In the diagram are shown the following forcing functions: inflow, outflow and the concentrations of nitrate and ammonium in the in- and outflow. Other forcing functions not shown are: solar radiation and temperature. The arrows in the diagram illustrate the processes numbered 1 to 18. If we want to proceed to a quantitative model, it is necessary to formulate these processes by use of mathematical expressions (equations).

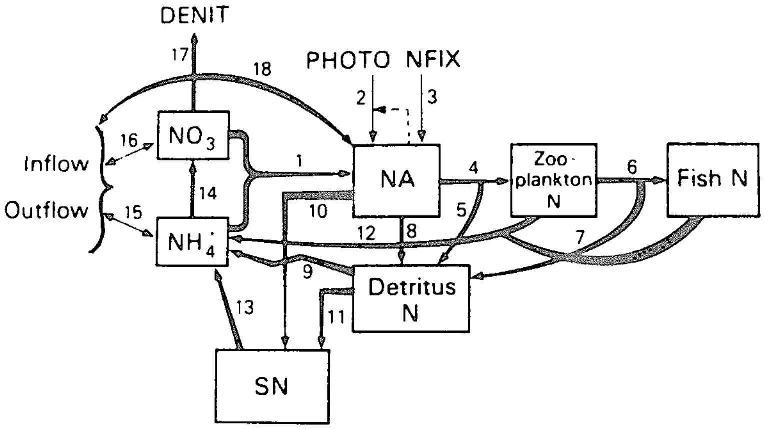

Figure 6.2 The nitrogen cycle in an aquatic ecosystem. The processes are: (1) Uptake of NO_3^- and NH_4^+ by algae, (2) Photosynthesis, (3) Nitrogen fixation, (4) Grazing with loss of undigested matter, (5), (6) and (7) are predation and loss of undigested matter by predation, (8) Mortality, (9) Minerali- zation, (10) Settling, (11) Settling of detritus, (12) Settling, (13) Release from sediment, (14) Nitrification, (15), (16) and (18) Input/output, (17) Denitrification.

It is of great importance to verify and validate models. **Verification** is a test of the *internal logic* of the model. Typically questions in the verification phase are: Does the model react as expected? Will for instance increased discharge of phosphorus give a higher concentration of phytoplankton in a model concerned with the eutrophication of a lake? Is the model long-term stable? Does the model follow the law of mass conservation? etc.

Verification is therefore largely a subjective assessment of the behaviour of the model. To a large extent verification will inevitably go on during the use of the model before the calibration phase, which has been mentioned above.

Validation must be distinguished from verification, but previous use of the words has not been consistent. Validation consists of an objective test on how well the model outputs fit the data.

6.3 MODELLING IN PRACTICE

Three important issues related to the application of models will be touched in this section:

1. Which procedure should a modeller follow to avoid mistakes and get the best possible results?

2. Which complexity of the model should be selected to obtain the maximum knowledge from the available data?

3. How to get a good accordance between data and objectives of the model.

The use of models in the ecological context is relatively new and few guides are therefore available for the construction of ecological management models. A tentative guideline is presented in Fig. 6.3.

In addition to defining the problem and its parameters in space and time, it is important to emphasize that this procedure is unlikely to be correct at the first attempt, and so there is no need to aim at perfection in one step. The main requirement is to get started (Jeffers, 1978). All ecosystems have a distinctive character and a comprehensive knowledge of the system that is going to be modelled is often needed to get a good start.

It is difficult to determine the optimum number of subsystems to be included in the model for an acceptable level of accuracy, and often it is necessary to accept a lower level than intended at the start due to a lack of data.

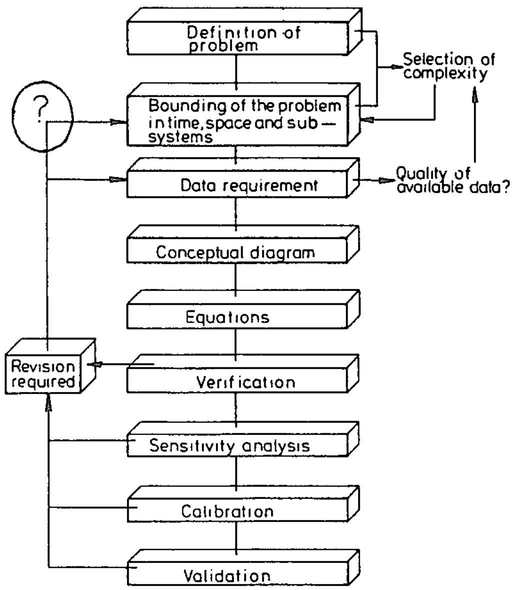

Figure 6.3 A tentative modelling procedure.

It has been argued that a more complex model should be able to account more accurately for the complexity of the real system but this is not true. Som additional factors have to be included in this considerations. As increasing number of paramberts are added to the model there will be an increase in uncertainty. The parameters have to be estimated either by observations in the field, by laboratory experiments or by calibrations, which again are based on field measurements. Parameter estimations are therefore never errer free. As these errors are carried through into the model they will contribute to the uncertainty of the prediction derived from the model, and there seems therefore to be some great advantage in reducing the complexity of models.

Some ecologists argue that ignorance of species diversity increases the risk of neglecting important elements of their dynamics. However, comparison of models with different complexities (Jørgensen et al., 1978 and 1981) demonstrates that the deviations of simpler models from alternative models, which take biological diversity into account, might be negligible for the purpose of the model. This trade off between complexity and simplicity in the choice of model is one of the most difficult modelling problems. Some attempts have been made to provide some genral rules. The method published by Jørgensen et al. (1977) measures the *response* of the model to more state variables and concludes that only the major influences of importance for the problem in focus should be included in the model. The method might also be interpreted as a sensitive test on the addition of state variables. The selection of the model complexity will be discussed further below.

Once the model complexity, at least at the first attempt, has been selected, it is possible to conceptualize the model (e.g. in the form of a diagram such as those shown for the nitrogen cycle in fig. 6.2). This will give information on, which state variables and processes are required in the model. For most processes a mathematical description is available, and most of the parameters have, at least within limits, known values from the literature. Tables of parameters used in ecological models can be found in Jørgensen et al. (!979).

It is possible at this stage to set up alternative equations for the same process and apply the model to test the equations against each other. However, the many ecological processes not included in the model, have some influence on the processes in the model. Furthermore, the parameter values used from the literature are often not fixed numbers, but are rather indicated as intervals. Biological parameters can most often not be determined with the same accuracy as chemical or physical parameters due to changing and uncontrolled experimental conditions. Consequently, calibration by the application of a set of measured data is almost always required. However, the calibration of several parameters is not realistic. Mathematical calibration procedures for ten or more parameters are not available for most problems. Therefore, it is recommended that sound values from the literature are used for all parameters, and that a sensitivity analysis of the parameters (see Fig. 6.3) is made before the calibration. The most sensitive parameters should be selected, as an acceptable calibration of 4-8 parameters is possible with the present techniques.

If it is necessary to calibrate 10 parameters or more it is advantageous to use two different series of measurements for the calibration of five parameters each, preferably by selecting measuring periods where the state variables are most sensitive to the parameters calibrated (Mejer et al., Jørgensen et al., 1981). It is of great importance to make the calibration on the basis of reliable data; unfortunately, many ecological models have been calibrated against inaccurate information.

It is characteristic of most ecological models that analysis and calibration of submodels are required. If ecological models are build without the knowledge of the ecosystem and its subsystems, they are often not realistic. These considerations are included in the procedure indicated above for the calibration and also in the modelling procedure presented in Fig. 6.3.

After the calibration it is important to validate the model, preferably against a series of measurements from a period with changed conditions, e.g. with changed external loading or climatic conditions.

The right complexity cannot, as already discussed, be selected generally. It seems that there has been a tendency rather to choose too complex rather than too simple a model, probably because it is too easy to add to the complexity: It is far more troublesome to obtain the data that are necessary to calibrate and validate a more complex model. As we have repeated here several times, it is necessary to select complexity on the basis of the problem, the system and the data available.

The tentative modelling procedure presented in Fig. 6.3 is only one among many workable procedures. However, the components of other possible procedures are approximately the same. The goal and the objectives of the model determine its nature. The steps: setting up a conceptual diagram, verification and validation are repeated in all procedures. As mentioned calibration and thereby sensitivity analysis might sometimes be redundant, when the parameters already are known with sufficient accuracy.

Modelling should, however, be considered an iterative process. When the model in the first instance has been verified, calibrated or validated, new ideas will emerge on how to improve the model. The modeller will again and again wish to build new data, knowledge and experience either from his own experiments or from the scientific literature into the model; this implies that he at least to a certain extent must go through the entire procedure again to come up with a better model. The modeller knows that he can always build a better model, which has higher accuracy, is a better prognosis tool or contains more relevant details than the previous model. He will approach the ideal model asymtotically, but will never reach it. However, *limited resources* will sooner of later stop the iteration and the modeller will declare his model to be good enough within the *given limitations.*

An example might be used to describe a model development:

1. A conceptual model was set up based upon a conprehensive study of Lake Glumsø in 1973 (Jørgensen et al., 1973).

2. This first model could not be used to set up a prognosis, as it was only a conceptualization of the ecological knowledge on the lake as an ecosystem. The objectives for the next step was to establish a relationship between eutrophication (measured by the concentrations of phytoplankton and by the transparency) and the nutrient input to the lake. Consequently a **mathematical model**, which focused on eutrophicaion, was made on basis of additional data. The model was calibrated and validated satisfactorily (Jørgensen, 1976).

3. During the following two years several **possible improvements** of the model were tested, which resulted in a slughtly changed model and improved calibration and validation. That model was used **to set up prognosis** for various management strategies, which could be compared more objectively (Jørgensen et al., 1978).

4. The experience with model calibration and validation made it clear, that the available data did not reflect adequately the dynamics of the most important state variable in the model: phytoplankton. The sampling frequency during the period 1973-76 was monthly, and it was therefore attempted to increase the sampling frequency to 3-4 times a week during the spring and summer bloom period to obtain better data for a more accurate calibration (Jørgensen et al., 1981).

5. A diversion of the waste water took place in 1981, which made it possible to validate the prognosis set up in 1978. Previously the model was validated under unchanged nutrient loadings, but it was an open question, whether a significant reduction in the nutrient loadings would cause such changes in the ecosystem, that the previously developed model would be invalid. Simultaneously with the prognosis validation, further possible improvements were tested and a few changes adopted. The validation of the prognosis gave under all circumstances the clear result, that the model was a good prognosis tool, but further improvements could be induced byu use of a current change of the most crucial parameters **to account for the changes in species composition** observed by the nutrient reduction (Jørgensen et al., 1986 and Jørgensen, 1986).

6. Further improvements seem therefore to take the direction of incorporation of dynamic structure into the model to improve the model ability to make predictions under radically changed circumstances.

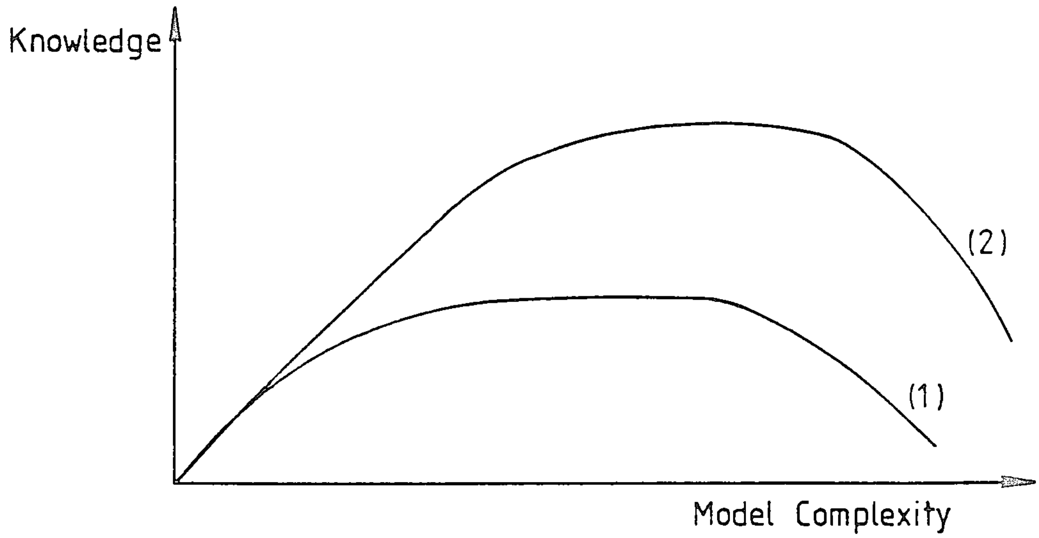

Figure 6.4 Knowledge plotted versus model complexity measured f.inst. by the number of state variables. The knowledge increases up to a certain level. Increased complexity beyond this level will not add to ones knowledge about the modelled system. At a certain level ones knowledge might be decreased. (2) corresponds to an available data set, which is more comprehensive or has a better quality than (1).

It is a general assumption that a model may be made more realistic by adding more and more connections, up to a point. Addition of new parameters after that point does not contribute further to improved simulations, but on the contrary more parameters imply more uncertainty, because of the possible lack of information about the flows, which the parameters quantify. Given a certain amount of data, the addition of new state variables or parameters beyond a certain model complexity does not add to our ability to model the ecosystem, but only adds unaccounted uncertainty. These ideas are visualized in Fig. 6.4. The relationship between knowledge gained through a model and its complexity (f.inst. measured as the number of state variables or the number of connectivities) is shown for two levels of data quality and quantity. The question under discussion can be formulated with relation to this figure: How can we select the complexity and the structure of the model to assure that we are on the optimum for "knowledge gained", or the best answer to the question posed to the model.

Costanza and Sklar (1985) have examined 85 different models and found that the relationship shown in Fig. 6.4 was valid.

The results from this mode review have some interesting scientific perspectives. In the past, scientists have tended to narrow their questions in order to achieve higher accuracy. This leads to models with low complexity but high descriptive accuracy. The results say much about little.

Nature is however complex and it becomes impossible to describe reactions of all species to the combinations of all possible impacts (forcing functions) **by use of accurate answers to narrow questions.** In physics it is impossible to know simultaneously the accurate location and velocity of a particle. This is in accordance with the uncertainty relations by Heisenberg, and can be explained by Bohr's complementarity principle: the observer effects the object. In ecology we have a similar uncertainty relation: all components and processes cannot be described accurately at the same time. **The product of the number of elements in the model and the descriptive accuracy of the model has an upper limit and the trade off for the modeller is between knowing much about little and little about much.** The complexity of nature can only be described by statistical high number of elements and therefore scientists have recently been looking at nature more comprehensively from a viewpoint of models and systems. This has enabled us to know a little more about much. In accordance with Costanza and Sklar, we therefore have to **construct models with high effectiveness, this is a function of both how much it attempts to explain** (articulation) **and how well it explains that, which was attempted** (descriptive accuracy).

6.4 ENVIRONMENTAL MANAGEMENT MODELS

There is no principal difference between scientific and environmental management models. Environmental management models have, on the other side, some characteristic features, which will be presented in this chapter.

The management problem to be solved can often be formulated as follows: if certain forcing functions (management actions) are varied, what will be the influence on the ecysystems state? The model is used to answer this question or in other words to predict, what will change in the system, when forcing functions are varied with space and time.

The term **control functions** is used to indicate forcing functions, that can be controlled by man such as consumption of fossil fuel, regulation of water level in a river by a dam, discharge of pollutants or fishery policy.

A certain class of environmental management models is named control models. They differ from other such models by the content of the following two elements:

1. a quantitative description of control processes
2. a formalization of objectives and evaluation of achievements.

The difference between control models and other environmental management models can best be illustrated by an example. The eutrophication model presented in next section can be used as a management model. If we find the model response to various input of nutrients, we get the corresponding scenarios as model output. Among these scenarios the manager can select the one, that he prefers from an ecological-economic viewpoint. The model is used as an environmental management tool, but it is not a control model, which needs to formulate a goal f.inst. that we want to achieve, within a certain period of time, a certain transparency of lake water. Furthermore, we must introduce into the model a veriable input of nutrients and find by use of the model the relation between the transparency and the nutrients input. The manager find directly from this relation which nutrients inputs, he must select to achieve his goal. It requires with other words some additional equations and concepts to be introduced into the model to construct a control model. In many cases this is quite feasible, but it adds to the complexity of the model. In cases where the control function can be varied continuously the advantages of control models are often sufficient to justify the additional complexity of the model, but if only a few possibilities are available, it hardly. pays to construct a control model.

In the case of eutrophication there are only a few methods able to reduce the nutrient inputs, which can be varied easily in accordance with the known efficiency of these methods or combinations of methods. The management problem in this case is: which method to select among a few possibilities? A question, which can be answered simply by comparison of the corresponding scenarios.

In the case, where objectives are multiple, not all the formulated goals might be achieved simultaneously. Some of the goals might even be contradictory. Several methods are available in operation research to solve such multi goal problems: linear transformation, use of control indices, use of metrics in goal function space, Pareto methods etc. (see Haimes, Hall and Freedman, 1975). Nevertheless, the final selection of a control function may ultimately be determined by subjective criteria, such as aesthetics which cannot be formulated. The final decision is in other words political.

A further step in complexity is the construction of ecological-economic models. As we gain experience in the construction of ecological and economic models, more and more ecological-economic models will be developed. It is often feasible to find a relation between a control function and the economy, but it is in most cases quite difficult to assess a relationship between the economy and the ecosystem state. What is f.inst. the economic advantages of an increased transparency? Ecological-economic models are useful in some cases, but should at the least be used with much precaution and the relation between economy and environmental conditions should be critically evaluated, before the results are applied.

This presentation of control and ecological-economic models could give the impression, that environmental models always are more complex than scientific models. This is not the case. Environmental management models have often more clear formulation of the objectives of the model than scientific models, which might render it more easy to selevt the complexity of the model in the first hand. Knowledge as to the needed predictive value of an environmental management model might also enable the modeller to reduce its complexity, while the scientific use of the model implies that the modeller rigorously questions the possibilities of complexity reductions.

Data collection is the most costly part of model construction. For many water quality models it has been found that the data collection has amounted to 80-90% of the total modelling costs. As complex models require far more data than simple ones, the selection of the complexity of environmental management models should be closely related to the environmental problem to be solved.

It is, therefore, not surprising that the most complex environmental management models have been developed for large ecosystems, where the economics involvment is great.

The predictive capability of environmental models can always be improved in a specific case by expansion of the data collection program and by increased complexity of the model, provided, of course, that the modellers are sufficiently skilled to know in which direction further expansion of the entire program has to develop. However, the relation between the economy of the project and the accuracy of the model is somewhat as shown in Fig. 6.5. The reduction in discrepancy between model and reality is lower for the next dollar invested in the project. But it is also clear from the shape of the curve in Fig. 6.5 that the error will never be complete eliminated: all model predictions have a standard deviation. This is not surprising to scientists, but it is often not realized by the decision makers, to whom the modeller has th present his results.

A validation, if carried out properly, can be used to determine the standard deviation. Model results used in environmental decisions should always be accompanied by an indication of the standard deviation on the prognosis and it is important to clarify the meaning of this standard deviation of this standard deviation to the decision maker. The modeller should even give recommendations as to how to use results and standard deviations in their proper context. Decision makers have often used standard deviations wrongly, when they were presented to them: as numbers, which indicate how much the costs could be reduced without any effect on environmental quality.

Engineers use safety factors to assure that a building or a bridge can last for a certain period of time with very low probability of breakdown to occur, even under extreme conditions. Decision makers would in such a case never interfere with the use of safety factors to account for the standard diviations of the engineer's model computations.

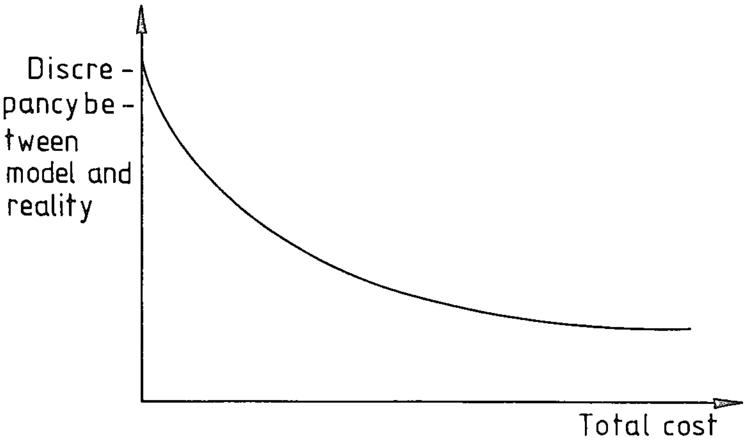

Figure 6.5 The more a skilled modeller invests in a model and in data collection the closer he will come to realistic predictions, but he will always gain less for the next dollar invested and he will never be able to give completely accurate predictions.

Nobody would propose to use a smaller or no safety factor at all to save some concrete and reduce the cost. The reason is obvious: nobody want to take the responsibility for even the smallest probability of a building or bridge collapsing.

When decision makers are going to take decisions on environmental issues, the situation is strangely enough different. Here he wants to use the standard deviation to save money not to assure under all circumstances high environmental quality. It is therefore the modellers duty to explain to the decision makers the consequences of the various decision possibilities. A standard deviation of a prognosis for an environmental management model can, however, not always be translated into a probability, because we do not know the probability distribution. It might hardly be one of the common distribution functions, but it is possible to use the standard deviation qualitatively or semiquantitatively and translate by use of words the meaning of the results. The civil engineers are actually more or less in the same situation and they have succeeded in convincing their decision makers.

Why should the environmental modeller not be able to do the same?

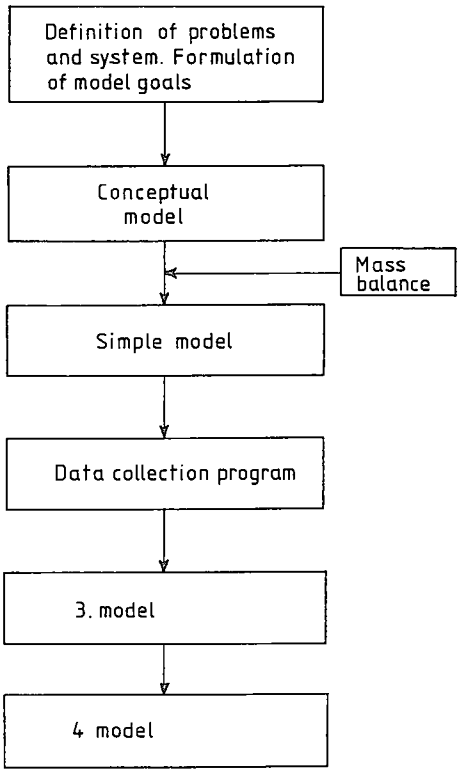

Figure 6.6 Scheme for development of a complex management model.

It is often advantageous to attack an environmental problem in the first hand by use of simple models. They require very few data and can give the modeller and the decision maker some priliminary results. If the modelling project is stopped at this stage for one or another reason, a simple model is still better than no model, because it will at least give a survey of the problem.

The simple model is, furthermore, a good starting point for the construc- tion of more complex models. In many cases the construction of a model is carried out as an iterative process, as mentioned in section 6.3. In Fig. 6.6 is shown how a stepwise development of a complex model might take place. The first model step is here as in Fig. 6.3 a conceptual model. It is used to get a survey of the processes and state variables in the system. The next step is a simple model, which is even calibrated and validated. It is used to set up a data collection program for a more comprehensive program, which is used for a model, which is close to the final selected version. Often, however, as is also shown in Fig. 6.6 the third model will in use reveal some weaknesses, which are attempted eliminated in the fourth version. It seems at the first glance to be a very cumbersome procedure, but as data collection is the most expensive part of the modelling, as mentioned above, it will require less resources to construct a preliminary model to use for optimization of the data collection program. It might be added that Fig. 6.6 can be considered a formalization of the iterative procedure that many modellers are forced to use anyhow and that a planning of these steps at an initial phase of the project alwas is advantageous.

A simple mass balance scheme is also recommendable to use for biogeochemical models (see chapter 5). The mass balance will indicate what posibilities we have for reduction or increase of a concentration, which, of course, is crucial for environmental management.

Table 6.1
Examples of sources

Source	Examples
Point sources	Waste water (N, P, BOD), SO_2 from fossil fuel discharge of toxic substances from industries
Non point man made sources	Agricultural use of fertilizers, deposition of lead from vehicles, contaminants in rain water
Non point natural sources	Run-off from natural forests, deposition on land of salt originated from the sea

Point sources are usually more easy to control than man made non-point sources, which again usually can be controlled better than natural sources. Examples of these three types of sources are given in Table 6.1. We can also distinguish between local, regional and global sources. As the mass balance indicates the quantities it is possible to conclude as to which sources to concentrate on first. If f.inst. a non-point regional source of pollutants is dominating it might be useless to eliminate small local point sources first, unless, of course, this might have some political influence on the regional decisions.

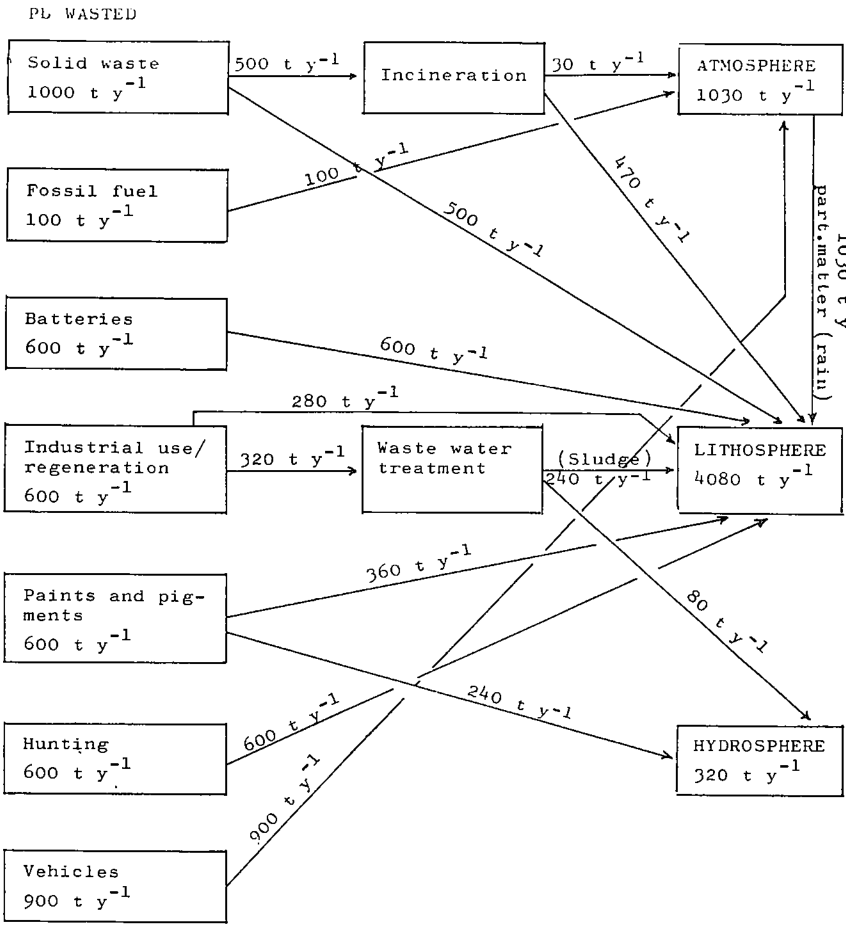

Figure 6.7 The dispersion of lead losses to the environment. (Denmark 1969).

Fig. 6.7 shows a mass balance model. From the model can be seen that diffuse contamination of lead is caused by lead in gasoline, which is also reflected in the lead concentration of lake sediment. Because of the diffuse character the lead will contaminate uncontrollably, whereas most of the lead in waste water can be removed by a proper treatment method or even recovered. As lead is toxic it is harmful in food items and water. It is therefore understandable that lead has been banned in gasoline in many countries or at least the allowed concentration reduced considerably.

It has been touched upon already that the modeller and the decision maker should understand each other. It is here recommendable to let the decision maker follow the model construction from the very first phase to get acquainted with its strength and the shortcomings of the model. It is also important that the modeller and the decision maker together formulate the objectives of the model and interprete the model results.

Communication between the decision maker and the modeller can be facilitated in many ways, and often it is in the hand of the modeller to do so. If the model is built as a menu system as presented by Mejer (1983) it might be possible in few hours to teach the decision maker, how to use the model and that will, of course, increase his understanding of the model and its results. If an interactive approach as presented by Fedra (1983) is applied it is furthermore possible for the decision maker to visualize a wide range of methods to give the best possible decision as to what happens in the system by use of various management strategies. It is under all circumstances recommendable to invest time in a good graphic presentation of the results to the decision maker. Even he has been currently informed about the model project in all its phases, he will hardly understand the background and assumptions of all model components. Therefore it is important that the results including the main assumptions, shortcomings and standard deviations are carefully presented by an illustrative method.

6.5 ENVIRONMENTAL PROBLEMS AND MODELS

We are not yet that far advanced in environmental modelling, that model results can be used solely. The model should never be used as decision maker, but should rather be considered as a very useful tool in the decision process. This implies that the modelling results should be clearly and illustratively presented and be considered an important component in the discussion of which decision to select. Side effects, the interpretation of the prognosis, implications of the prognosis accuracy etc. are elements which might be considered in such a discussion.

If a good environmental model is available, it is a very powerful tool in the decision-making process. A wide range of environmental problems has been modelled during the last 10-15 years. They have all been of important assistance to the decision makers and with the rapid growth in the use of environmental models, the situation will only improve in the nearest future. Obviously, we do not have achieved the same level of experience for all environmental problems.

Note that we need far more experience in environmental modelling of large scale problems, such as the regional distribution of airborne pollutants and the water quality of the sea or an entire catchment area. Our knowledge and experience about the distribution and effect of toxic substances and the stability of ecosystems including the significance of species are, generally, limited. Some case studies of toxic substances distribution and effect are well examined, but our experience is still much too limited when the great number of toxic substances is taken into account.

The use of models in environmental management is growing. Particularly models have been well developed in lake management.

Models are widely used in several European Countries, in North America and in Japan, but more and more countries take up the application of models by environmental agencies. Through the journal "Ecological Modelling" and ISEM, International Society for Ecological Modelling, it is possible to follow the pregresses in the field. This "infrastructure" of the field facilitates the communication and accelerate the exchange of experience and thereby the growth of the entire field of ecological modelling. Soon there will be a need for a model bank, where the user can obtain information about existing models, their use and characteristics. It is not possible to transfer a model from one case study to another as stated throughout the book and it is difficult to transfer a model from one computer to another, unless it is exactly the same type of computer, but it is often a great help to get the experience gained by somebody else in modelling a similar situation at some other place in the world.

This touch on the problem of generality of models. Few models have been used on several case studies to give a wide experience on this important matter. The eutrophication model presented in next section has been used on a wide range of case studies included lakes in the temperate and the tropical zone, shallow and deep lakes and even fjords. The experience gained by these case studies is illustrative, but does not necessarily represent general properties of models.

6.6 OVERVIEW OF LAKE MODELS

Several eutrophication models with a wide spectrum of complexity have been developed. As for other models the right complexity of the model is dependent on the available data and the ecosystem. Table 6.2 reviews various eutrophication models.

Table 6.2
Various Eutrophication Models

Model	Number of state variables per layer or segment	Nutrient considered	Segments	Dimension (D) or Layers (L)	Constant Stoichometrics (CS) or independent Nutrient Cycle (NC)	Calibrated and/or Validated	Number of case studies in literature
Vollenweider	1	P (N)	1	1L	CS	C + V	many
Imboden	2	P	1	2L, 1D	CS	C + C	3
O'Melia	2	P	1	1D	CS	C	1
Larsen	3	P	1	1L	CS	C	1
Lorenzen	2	P	1	1L	CS	C + C	1
Thomann 1	8	P, N, C	1	3L	CS	C + V	1
Thomann 2	10	P, N, C	1	7L	CS	C	1
Thomann 3	15	P, N, C	67	7L	CS	-	1
Chen & Orlob	15	P, N, C	sev.	7L	CS	C	min. 2
Patten	33	P, N, C	1	1L	CS	C	1
Di Toro	7	P, N	7	1L	CS	C + V	1
Biermann	14	P, N, Si	1	1L	NC	C	1
Canale	25	P, N, Si	1	2L	CS	C	1
Jørgensen	17	P, N, C	1	1-2L	NC	C + V	17
Cleaner	40	P, N, C, Si	sev.	sev. L	CS	C	many
Nyholm	7	P, N	1-3	1-2L	NC	C + C	13

The table indicates the characteristic features of the models, the number of case studies it has been applied (of course with some modification from case study to case study, as a general model is nonexisting and as site specific properties should be reflected in the selected modification) and whether the model has been calibrated (C) and validated (V).

Some of the most simple models, that can be used in a data-poor situation are presented below. These models give the reader a good impression of problems involved in modelling the eutrophication process.

Simple eutrophication models are based upon three steps:

1. Determination or calculation of nutrient loading
2. Prediction of the nutrient concentration (usually only one nutrient is considered
3. Prediction of eutrophication.

6.7 SIMPLE VERSUS COMPLEX MODELS

In section 6.3 it was emphasized that the model should consider the problem, the ecosystems and the data, and that it is of importance to select a model complexity, which the data can bear. Consequently, it is not always possible to develop a model, which gives the predictive capacity that is needed for a given problem. The modeller must here be aware of the limitations of his model and either present these limitations together with his model or attempt to get better data.

Determination of nutrient balances is the basic of all eutrophication models. It is possible by measurement of the concentrations and flow rates of in- and outputs. Alternatively it is possible to calculate the nutrient loading as demonstrated below, although it is only recommendable to use the calculation method, when data are not available.

I Calculation of the nutrient loading of lakes

The first step is to set up a nutrient balance for the lake system, see chapter 5. If observations are not available, it is possible to use estimation methods, as shown below.

a) Natural P and N loads from land

Table 6.3 shows a phosphorus-, E_P, and nitrogen-, E_N, export scheme based on a geological classification.

The figures are based on an interpretation of the following references: Dillon and Kirchner (1975); Loenholdt (1973) and (1976); Vollenweider (1968) and Loehr (1974).

To calculate the natural nutrient loading to a lake, one must know 1) the area A1 of the watershed of each tributary to the lake, and 2) classify each as to geology and land use.

Table 6.3
Export Scheme of Phosphorus, E_P, and Nitrogen, E_N. (mg m^{-2} y^{-1})

	E_P Geological classification		E_N Geological classification	
Land use	Igneous	Sedimentary	Igneous	Sedimentary
Forest runoff				
Range	0.7-9	7-18	130-300	150-500
Mean	4.7	11.7	200	340
Forest + pasture				
Range	6-12	11-37	200-600	300-800
Mean	10.2	23.3	400	600
Agricultural Areas				
Citrus	18			2240
Pasture	15-75			100-850
Cropland	22-100			500-1200

The total amount of phosphorus, I_{Pt} , and nitrogen, I_{Nt} , supplied to the lake from the land is therefore calculated by the use of the following equations:

$$I_{Pt}\ (mg\ y^{-1}) = \sum_{i=1} A_t\ (m^2) * E_P\ (mg\ m^{-2}\ y^{-1}) \qquad (6.1)$$

$$I_{Nt}\ (mg\ y^{-1}) = \sum_{i=1} A_t\ (m^2) * E_N\ (mg\ m^{-2}\ y^{-1}) \qquad (6.2)$$

b) Natural P and N loads from precipitation

Table 6.4 is a compilation of the following references. Armstrong and Schindler (1971), Dillon and Rigler (1974) and Jørgensen et al. (1973). Based upon the annual precipitaion of P (mm y^{-1}) it is possible to find the supply of phosphorus I_{PP} and nitrogen I_{NP} from precipitation:

$$I_{PP}\ (mg\ y^{-1}) = P\ C_{PP}\ A_S \qquad (6.3)$$

$$I_{NP}\ (mg\ y^{-1}) = P\ C_{NP}\ A_S \qquad (6.4)$$

where A_S is the surface area of the lake, and C_{PP} and C_{NP} are the phosphorus and nitrogen concentrations in rain water (see Table 6.4).

Table 6.4
Nutrient Concentration in Rain Water (mg l^{-1})

	C_{PP}	C_{NP}
Range	0.025-0.1	0.3-1.6
Mean	0.07	1.0

c) Artificial P and N loads

The calculation of the artificial nutrient supply to a lake must necessarily be based on per capita and yearly figures, and great care must be taken in selecting the appropriate value. The following points must be taken into consideration:

1. The discharge per capita and per year is approx. 800-1800 g P and 3000-3800 g N.
2. Mechanical treatment removes 10-15% of the nutrients.
3. Biological treatment removes 10-15% of the nutrients.
4. Chemical precipitation removes 80-90% of the phosphorus.
5. The retention coefficient, R, of total phosphorus for septic filter beds of

different characteristics are shown in Table 6.5 (after Brandes et al., 1974). The retention coefficient of total nitrogen for septic tile filter beds are of the order 0.01-0.1.

Table 6.5
Retention Coefficients. (Brandes et al., 1974) D = grain size

Filter bed	R_S
4% sed. mud 96% sand (70 cm)	0.76
75 cm sand D = 0.3 mm	0.34
75 cm sand D = 0.6 mm	0.22
75 cm sand D = 0.24 mm	0.48
75 cm sand D = 1.0 mm	0.01
10% sed. mud 90% sand (37 cm)	0.88
50% limestone 50% sand (37 cm)	0.73
Silty sand (70 cm)	0.63
50% clay silt 50% sand (37 cm)	0.74

Based upon the considerations indicated above, the P load (I_{Pw}) and N load (I_{Nw}) can be found.

II Prediction of the nutrient concentration in a lake

Vollenweider (1969) assumed that the change in concentration of phosphorus in a lake with time is equal to the supply added per unit volume minus loss through sedimentation and the loss by outflow.

$$d\frac{[P]}{dt} = \frac{I_{Pt} + I_{PP} + I_{Pw}}{V} - s\,[P] - r\,[P] \qquad (6.5)$$

where [P] represents the total phosphorus concentration (mg l^{-1}), V is the lake volume (l), s is the sedimentation rate (y^{-1}) and r the flushing rate (y^{-1}); r is equal to Q/V where Q is the total volume of water flowing out per year (l y^{-1}).

This equation can be solved analytically:

$$[P] = \frac{I_P}{V\,(s + r)} - \left(1 - \frac{V(r + s)\,[P_0]}{I_P}\right) e^{-(r + s)\,t} \qquad (6.6)$$

$$I_P = I_{Pt} + I_{PP} + I_{Pw} \qquad (6.7)$$

The equations for [N], the nitrogen concentration, are parallel to those for [P]. The steady state solution is:

$$[P] = I_P / r + s \tag{6.8}$$

$$[N] = I_N / r + s \tag{6.9}$$

where

$$I_N = I_{Nt} + I_{NP} + I_{Nw} \tag{6.10}$$

As seen it is necessary to calculate or measure Q. In some cases the long-term average inflow, Q_{in}, can be calculated as:

$$Q_{in} = A_t * P (1 - k') \tag{6.11}$$

where k' is the ration of evapotranspiration to precipitation. k' is often known for a given geographical area, and Q can be found on the basis of a water balance:

$$Q = Q_{in} + A_s * P - A_s * E_V$$

where E_V represents the evaporation in mm y^{-1} m^{-2}.

The only alternative to these calculations is to measure Q or Q_{in}. It is rather difficult to determine s, the sedimentation rate. However, an alternative retention coefficient, R (equal to the fraction of the loading that is not lost via the outflow) may be used, Kirchner and Dillon (1975) determined by multiple regression analysis that R was highly correlated with Q/A_s, the areal water loading (m^3/m^2y).

The equation for the prediction of R is:

$$R = 0.426 \exp \left(-0.271 \frac{Q}{A_s} \right) + 0.574 \exp \left(-0.00949 \frac{Q}{A_s} \right) \tag{6.12}$$

If the lake in question has one or more lakes upstream that are sufficiently large to retain a significant amount of the total nutrient exported from their respective portion of the water shed, this can be taken into account by calculating the supply to the upstream lake, the lakes retention coefficient, R_A, and multiplying the supply by $(1 - R_A)$ to give the fraction transfer to the downstream lake.

The above mentioned retention coefficient was generated for phosphorus. Calculations carried out in 18 lake studies in Scandinavia have shown that R is relatively 10-20% lower (average 16%) for nitrogen than for phosphorus.

The use of R instead of s leads to the following basic equation:

$$[P] = \frac{I_P (1 - R)}{V_r} - (1 - \frac{V_r P_0}{I_P (1 - R)}) e^{-(t/1-R)\ t} \qquad (6.13)$$

and for the steady state situation:

$$[P] = \frac{I_P (1 - R)}{V_r} \qquad (6.14)$$

The equations for nitrogen are parallel; only a 16% lower R value is used.

Dillon and Rigler (1974) and Sakamoto (1966) have developed a relationship for estimating the average summer chlorophyll in a concentration (chl.A) with the N:P ratio of the water > 12:

$$\log_{10} (chl.A) = 1.45 \log_{10}(P) * 1000 - 1.14 \qquad (6.15)$$

In case the N:P ratio is < 4 the following equation, based upon eight case studies was evoled:

$$\log_{10} (chl.A) = 1.4 \log_{10}(N) * 1000 - 1.9 \qquad (6.16)$$

(N) and (P) are expressed as mg l^{-1} while (chl.A) is found in $\mu g\ l^{-1}$. if the N:P ratio is between 4 and 12, the use of the smalles value of (chl.A) found on the basis of the two equations is recommended. Dillon et al. (1975) have set up a relationship between the Secchi disc transparency, SE and (chl.A), which is shown in Fig. 6.8.

The simple model presented above will never be as good a predictive tool as a model based on more accurate data and taking more processes into consideration.

However, the semiquantitative estimations, which can be obtained by use of the simple model presented, are better than none at all.

Methods to estimate the input of P and N to a lake, from natural and artifical sources, are considered. From the above shown it is possible to estimate the P concentrations in the lake water as a function of time.

The N concentration can be estimated by a parallel set of equations.

These considerations can be translated into chlorophyll, a concentration can be determined and in Fig. 6.8 the transparency can be found when (chl.A) is known.

It is possible in this way to test different waste water treatment programmes.

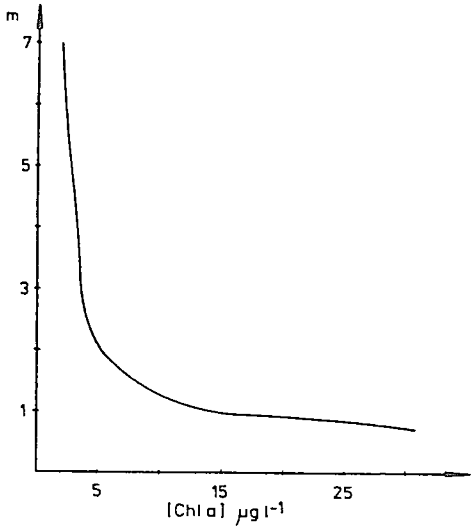

Figure 6.8: Transparency versus (m) (chl.A).

Fig. 6.9 gives the conceptual diagrams of a complex model. The process equations are given and similar diagrams are valid for nitrogen (see Fig. 6.2) and carbon. Sometimes also silica are considered, if diatoms contribute significantly to the biomass. For details on construction of complex lake management models see Jørgensen (1986).

Construction of reservoirs requires an environmental impact assessment **before** the dam is built. Data from the not yet existing reservoir are obviously not available, but it is still possible to obtain information, which are useful for development of the model. A tentative list of questions could be:

1. Which concentrations of water constituents does the river water have?

2. Which input from point- and non-point sources should be expected?

3. What capacity will the sediment in the reservoir have for accumulation of P-, N- and toxic substances?

4. Which data are available from a reservoir with the same

bio-geochemical conditions?

5. Which model experience is available from a reservoir with as many similarities as possible? What is the difference between the two reservoirs and how should this influence the model?

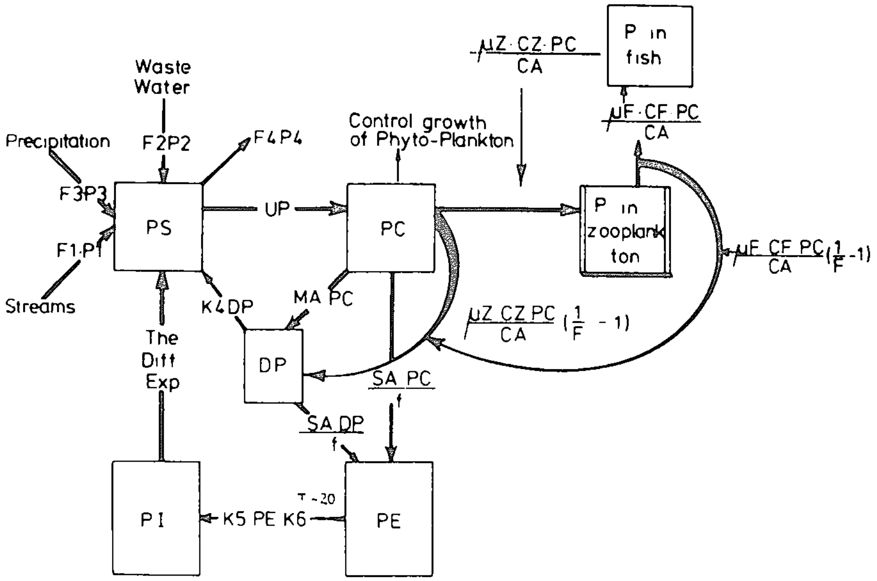

Figure 6.9: The P-cycle. The equations for the processes are included in the diagram.

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CHAPTER 7

REMEDIAL TECHNIQUES

7.1 INTRODUCTION

A wide spectrum of remedial techniques are available to day, which implies that the selection of the right combination of methods requires considerable considerations. The basis for development of a good management plan is a comprehensive knowledge to the sources of pollution and the ecosystem properties. To obtain this knowledge is already a complex problem, as illustrated in Table 7.1, where the potential sources and sinks of nitrogen and phosphorus are listed.

Table 7.1
Potential sources of Nitrogen and Phosphorus and routes of sinks.

Natural	Anthropogenic
Sources:	
Leaching from:	Leaching from:
- swamps - uncultivated land - forests Soil erosion Rain water Deposited leaves, etc. Aquatic birds and animals in general Ground water Nitrogen fixing Recycling of sediments	- farm areas, arable land pastures, including fertilizers and animal excrement; - urban leaching - refuse and domestic and industrial liquid waste - garbage dumps, etc.
Sinks:	
Effluents Denitrification Sinks toward ground water Sinks toward sediments	- Removal of water - Fishing - Removal of aquatic plants, etc.

Due to the complexity of the problem it is strongly recommended to apply mass balances and models, as presented in the two proceeding chapters, to overview the management possibilites (see also chapters 2 and 5).

The sources of pollution may either be point or non- point sources, which requires entirely different approaches to the problem. In principle are two types of remedial techniques available: environmental technology and ecotechnology. The first mentioned type attempt by use of water treatment technology to eliminate or reduce the undesired components in the inflowing waste water, while the latter type attempt to modify the ecosystem or its surroundings to accelerate the restoration process or reduce the concentrations of undesired components in the lake or in the natural inflowing water to the lake. Environmental technology is mainly used to solve the problems of the point sources, while ecotechnology is used to solve the problem of the non-point sources, to improve the resistence of the ecosystem to pollution or to accelerate the tranfer to a more favourable state. Environmental technology is an external control measure, while ecotechnology may be considered either an external or an internal control measure.

Optimum lake management strategy will in general require the application of a wide spectrum of methods, based on a combination of environmental technology and ecotechnology. It should not be exptected that a complex problem has a simple solution.

7.2 APPLICATION OF ENVIRONMENTAL TECHNOLOGY.

Waste water technology has progressed rapidly during the last two decades, and today a wide spectrum of waste water treatment methods are available, which meet almost all water criteria.

A survey of the most generally applied waste water treatment methods are, for both industrial and municipal waste water, is given in Table 7.2. The specific waste water problem, the method to solve it and the generally experienced removal efficiency is indicated in the table. These indications must, however, be used cautiously, as the efficiency depends on the compostion of the waste water, the temperature and pH. Table 7.3 summarizes in matrix form the relation between methods and waste water pollution parameters. here the efficiencies indicated are the best attainable, for instance the removal of heavy metals by precipitation will require calcium hydroxide to abtain the efficiency shown in the matrix.

The solution of a waste water problem often requires a combination of two or even more methods. in this case the overall efficiency, e, of a n-step treatment can approximately be computed from the following expression:

$$1 - e = (1 - e_1)^*(1 - e_2)^* \ldots\ldots\ldots\ldots\ldots\ldots (1 - e_n) \qquad (7.1)$$

where e_1, e_2,.....etc. are the efficiencies of the individual steps.

Table 7.2
Survey of generally applied waste water treatment methods

Method	Pollution problem	Efficiency
Mechanical treatment	Suspended matter removal	0.75-0.90
	BOD_5 reduction	0.20-0.35
Biological treatment	BOD_5 reduction	0.70-0.95
Chemical precipitation	Phosphorus removal	0.65-0.95
$Al_2(SO_4)_3$ or $FeCl_3$	Reduction of heavy metals concentrations	0.40-0.80
	BOD_5 reduction	0.50-0.65
Chemical precipitation	Phosphorus removal	0.85-0.95
$Ca(OH)_2$	Reduction of heavy metals concentrations	0.80-0.95
	BOD_5 reduction	0.50-0.70
Ammonia stripping	Ammonia removal	0.70-0.95
Nitrification	Ammonium is oxidized to nitrate	0.80-0.95
Active carbon adsorption	COD removal (toxic substances)	0.40-0.95
	BOD_5 reduction	0.40-0.70
Denitrification after nitrification	Nitrogen removal	0.70-0.90
Ion exchange	BOD_5 reduction (proteins, e.g.)	0.20-0.40
	Phosphorus removal	0.80-0.95
	Nitrogen removal	0.80-0.95
	Reduction of heavy metals concentrations	0.80-0.95
Chemical oxidation (e.g. with Cl_2)	Oxidation of toxic compounds (e.g. CN^- - N_2)	0.90-0.98
Extraction	Heavy metals and other toxic compounds	0.50-0.95
Reverse osmosis	Removes pollutants with high efficiency, but is expensive	
Disinfection methods	Reduction of microorganisms	High, but can hardly be indicated

As already mentioned, the application of the two Tables 7.2 and 7.3 only give approximate results, which must be used with caution. In practice more details will always be required, but first estimations, such as those shown in the two tables, are useful for first considerations of possible solutions to waste water pollution problems.

Table 7.3
Efficiency matrix relating pollution parameters and waste water treatment methods

	Susp. matter	BOD_5	COD	P-total	NH_4^+
Mechanical treatment	0.75-0.90	0.20-0.35	0.20-0.35	0.05-0.10	~0 ~0
Biological treatment*	-	0.75-0.95	0.65-0.90	0.10-0.20	0.05-0.10
Chemical precipitation	0.80-0.95	0.50-0.75	0.50-0.75	0.80-0.95	~0 ~0
Ammonia stripping	~0	~0	~0	~0	0.70-0.96
Nitrification	~0	~0	~0	~0	0.80-0.95
Active carbon adsorption*	-	0.40-0.70	0.40-0.95	~0.1	high**
Denitrification after nitrification	~0	-	-	~0	-
Ion exchange	-	0.20-0.40	0.20-0.50	0.80-0.95	0.80-0.95
Chemical oxidation	-	corresponding to oxidation	~0	~0	~0
Extraction	-	corresponding extraction of toxic compounds	~0	~0	~0
Reverse osmosis*		see Table 7.2			
Disinfection methods	-	much corresp. to appl. of chlorine, ozone, etc.			

Table 7.3 (continued)

	N-total	Heavy metals	E. coli	Colour	Turbidity
Mechanical treatment	0.10-0.25	0.20-0.40	- -	~0	0.80-0.98
Biological treatment*	0.10-0.25	0.30-0.65	fair	~0	-
Chemical precipitation	0.10-0.60	0.80-0.98	good	0.30-0.70	0.80-0.98
Ammonia stripping	0.60-0.90	~0	~0	~0	~0
Nitrification	0.80-0.95	~0	fair	~0	~0
Active carbon adsorption*	high**	0.10-0.70	good	0.70-0.90	0.60-0.90
Denitrification after nitrification	0.70-0.90	~0	good	~0	-
Ion exchange	0.80-0.95	0.80-0.95	very good	0.60-0.90	0.70-0.90
Chemical oxidation	~0	~0	~0	0.60-0.90	0.50-0.80
Extraction	~0	0.50-0.95	~0	~0	~0
Reverse osmosis*					
Disinfection methods			very high	0.50-0.90	0.30-0.60

7.3 THE APPLICATION OF ECOTECHNOLOGY

Ecotechnology - also named ecological engineering has emerged as an alternative technological approach during the last decade due to insufficient results obtained by sole application of environmental technology, see Jørgensen and Mitsch (1988). It offers a wide spectrum of possibilities, but they must work hand in hand with the environmental technology to achieve the best possible management plan.

These methods deal either with the non-point sources of pollution or attempt to assist the lake to return faster to its natural balance. The control measures may either be external or internal, as shown in Table 7.4, which gives an overview of the ecotechnological remedial measures.

Table 7.4
Remedial measures

I "External" Control Measures
1) Protection of Catchment Area
- Forestation
- Land use change
- Sewage treatment
2) Pre-impoundments
3) Nutrient Control in Inflowing River Waters

II "Internal" Control Measures
1) Physical Manipulations
a) mixing and thermal destratification
b) aeration, hypolimnetic oxygen inflation
c) selective water withdrawals
2) Chemical Manipulations
a) internal nutrient precipitation
b) sediment sealing and removal
3) Biota Manupulations
a) mechanical harvesting
b) chemical control measures (algicides, herbicides, insecticides)
c) biological control measures

The application of ecotehnology for restoration of lakes is very illustrative, because these methods have been widely applied on lakes ,and it can be clearly demonstrated that to achieve good results in lake management you need to play on several methods - as well environmental technological as ecotechnological methods - simultaneously. Pollution of lakes is a very complex problem and it can as pointed out in the introduction rarely be solved by the use of one (simple) method. It is not surprising that a good solution to a complex problem, requires a complex solution and that models have been widely used in the selection of lake management strategies to get the optimum overview of the complex problem involved.

Table 7.5 gives an overview of the ecotechnological methods, that are used in lake restoration. The names of the methods are indicated in the table, which problem they are used to solve and whether the methods are changing the forcing functions of the lake or are attempting to reach the natural balance faster than it otherwise would have been the case - or with other words whether the methods directly will change the mass balances of the lake or the methods will change the structure (the state variables) of the system. Indirectly all methods will change the mass balance and the structure more or less. The methods, that change the state variables of the systems, but do it by use of a new forcing function (for instance aeration) are indicated in Table 7.5 with F (+S).

Table 7.5
Ecotechnological methods applied in lake restoration

Method	Problem to solve	Direct Change of forcing function (F) or state variables (S)	Principle (see section 1.3)
Aeration	Oxygen depletion in hypolimnion. Release of P and Fe^{-} from sediment (eutrophication)	F (+S)	C
Siphon of hypo-limnion water	Removal of P and oxygenpoor water (eutrophication)	F	C
Nitrate to sediment	Reduce release of P from sediment (eutrophication)	F (+S)	C
Aeration with circulation	Eutrophication: depression of algal growth	S	C
Removal of upper sediment layer	Reduce release of P from sediment or remove toxic substances (eutrophica-tion and toxic substance pollution	S	C
Removal of P or algae from water	Eutrophication (reduce P/algae in water)	S	C
Wetland	Removal of N and P from non-point sources (eutrophication)	F	A(B)
Decreased reten-tion time	Reduce P and toxic substances concen-tration (eutrophication and toxic sub-stances pollution)	F	C
Precipitation of P in lake	Eutrophication (reduced P in water)	S	C
Precipitation of P in inflowing water	Eutrophication (reduced P input)	F	C
Addition of $Ca(OH)_2$	Change of pH	F (+S)	C
Coverage of sediment	Eutrophication	F (+S)	C
Preimpoundment	Eutrophication (reduce P-input)	F	B
Plastic beads or sheet dyes or soot	Reduce of high penetration (eutrophication)	F (+S)	C
pH-modification shock	Eutrophication (reduce inorganic carbon in water)	S	C

Another overview of the ecotechnological methods applied in lake restoration can be obtained by use of models. From eutrophication models we know that algae growth, A, is a function of light, L, soluble inorganic nitrogen, NS, soluble inorganic phosphorus, PS, soluble inorganic carbon, CS, the settling rate, S, the retention time , R, and the grazing rate G:

$$A = f(L,NS,PS,CS,S,R,G) \tag{7.2}$$

The methods can be classified (see Table 7.6) after which factor it changes either *in* the lake or by decrease of input or increase of output, i.e. by change of forcing functions. The principle of this classification may also be applied for toxic substance and acidification problems.

Artificial reaeration of lake water is included in this survey as it is widely used in lake restoration to obtain better oxygen conditions. It is therefore a method, which improve the redox potential for the lake water.

Anaerobic sediment will generally release more phosphorus than aerobic sediment as the latter contain iron in the oxidation state three , while the former contains iron in the oxidation state two. Iron (III) has a higher adsorption capacity to phosphorus than iron(II) and iron(III) phosphate is much more insoluble than iron(II)phosphate. These processes may cause a "run away" effect as increased eutrophication will mean a higher production of phytoplankton, which will settle and thereby give a high input of organic matter to the sediment. It becomes therefore anaerobic, which will mean enlarged release of phosphorus, which will cause more eutrophication etc. If the sediment gets sufficient anaerobic (low redox potential) sulphide formation may occur and as iron(II) sulphide is highly insoluble, this will further promote the release of phosphorus.It may be concluded that there is a closed relation between the redox conditions and the nutrients cycling in lakes.

Aeration may also be able to depress the eutrophication. It is achieved if the aerotor circulates the water as shown in Fig. 7.1. The water of the bottom layer is lifted by aeration and is replaced by the upper layer of water, which may be supersaturated with oxygen produced by the photosynthesis . The algae will be brought down to the dark hypolimnion, where the light conditions are unfavourable for algae growth. Fig.7.2 shows the profile of phytoplankton and oxygen concentration before and after aeration with water circulation (Kojima 1987) Table 7.7 shows the effects on the eutrophication measured in reservoirs with different depths. If the depth is more than 5-10 meters, the effect is as will be noted very pronounced.

Some of the methods serve two purposes - to improve the oxygen condition and to change the concentration of nutrients in the lake water.

This is the case when hypolimnion water is siphoned downstreams since hypolim- nion water generally has lower oxygen and higher nutrient concentrations.

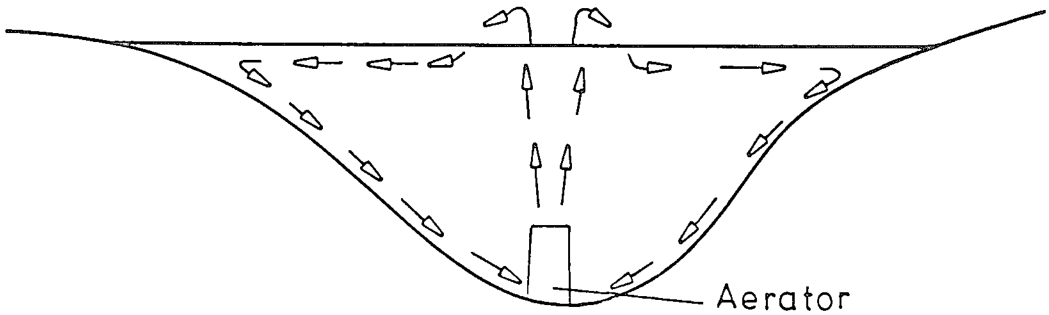

Figure 7.1 The circulation of water by use of an aerotor.

Often the upper layer of the sediment has higher nutrient concentrations than the deeper layers. Figure 7.3 illustrates this as it shows the phosphorus profile in a typical lake sediment. The phosphorus of the upper layer is either non-exchangeable as it is bound in insoluble chemical compounds or it is exchangeable f.inst. because it is organic bound and after decomposition of the organic matter it is released. Consequently, it will be an advantage to remove the upper layer of the sediment and thereby reduce the release of phosphorus from the sediment. This has been used only in one case - Lake Trummen in Sweden - and it was only partly a success as it will be discussed below. If the upper layer of the sediment contains toxic substances the method must be considered rather attractive, but since the method is expensive, it only seems applicable for small and very valuable lakes.

As seen from Table 7.5, a reduction of the retention time also has a positive effect on the eutrophication, but will also imply a smaller concentration of toxic substances, if that is considered a pollution problem to the lake. The method is realized by discharge of unpolluted water to the lake. For reservoirs it is possible to control the retention time by the dam. The use of dams will not only enable changes in the retention time, but also in the water depth and water volume. A longer retention time will in general mean an increased eutrophication and a larger volume will mean a decreased eutrophication. It is therefore necessary to use models to make prediction of the overall effect by these changes in the hydrological balance of the lake or the resevoir. A further complication is related to the soil exposed to the lake water at increased depth. It will be in an oxidized state and therefore in general have a great capacity for non-exchangeable phosphorus. If this new sediment surface is significant in area, an increased water depth may cause an essential change in the phosphorus balance of the entire lake.

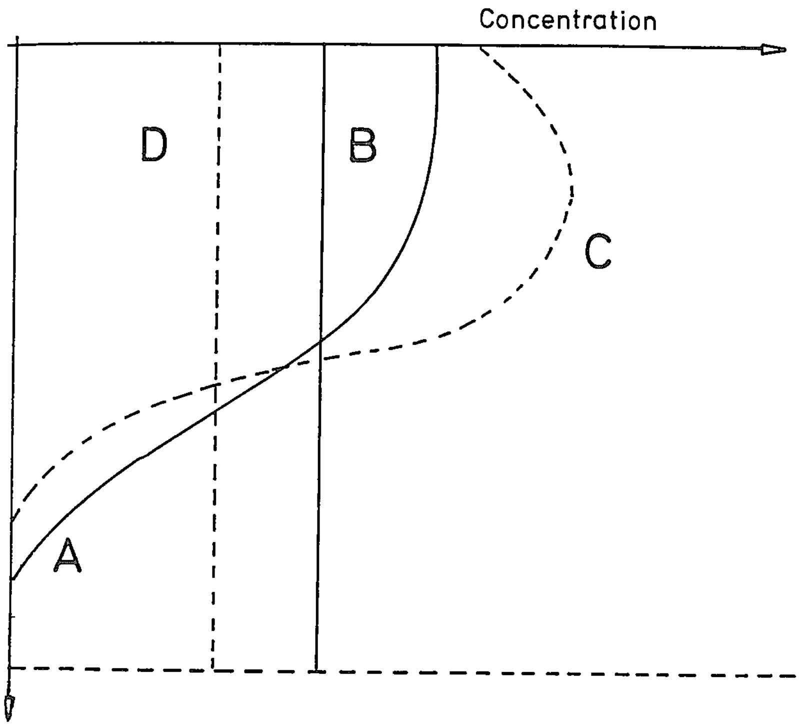

Figure 7.2 Oxygenconcentration before (A) and after (B) circulation. Phytoplankton concentration before (C) and after (D) circulation.

It is also possible to remove phosphorus from the lake water directly. The water is either pumped through an activated aluminiumoxide column which removes the phosphorus very effectively, or the water is filtrated for removal of the phytoplankton. The treated lake water is returned to the lake with a reduced concentration of respectively soluble phosphorus or of phytoplankton and thereby of the total concentration of nitrogen and phosphorus as result.

Precipitation directly in the water by use of aluminium sulphate or iron(III)chloride is also applicable. The method has, however, given less promising results in shallow lakes, as the wind may stir up the flocs formed by the precipitation. Precipitation of phosphorus in inflowing water has also been used (Bernhardt 1979 and 1981 a + b).

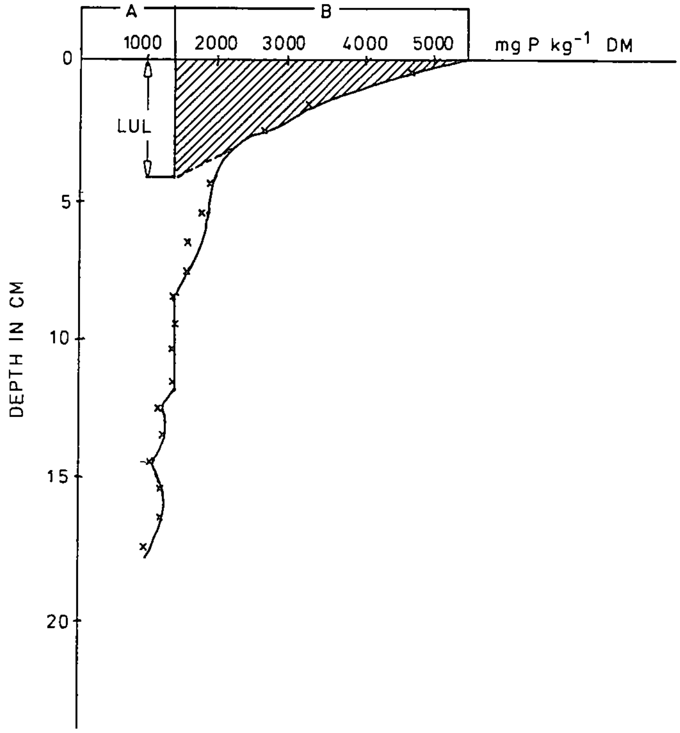

Figure 7.3 Phosphorus profile in typical lake sediment

If the sources of lake pollution are diffuse, the problem is in general more difficult to solve. The use of wetlands is often a workable method, which can be applied for the removal of non-point pollutants. Wetlands have often anaerobic sediment and therefore a high denitrification rate. In addition the wetland soil has a high capacity for uptake of phosphorus, pesticides and other pollutants. Finally, the plants of the wetlands take up phosphorus and nitrogen and even other pollutants and by harvest of the plants the pollutants will be removed.

A similar idea is behind the use of pre-impoundments. Lakes and reservoirs have a phosphorus retention capacity, which implies that the phosphorus concentration of the water leaving the lake is lower than in the water entering the water body (Rechow 1979, Rechow and Chapra 1983). Phosphorus retention increases with decreasing hydraulic retention time and mean depth and the phosphorus retention is also less for lakes or reservoirs with anoxic hypolimnion. Consequently, construction of a man made lake in front of another lake (this is named pre-impoundment) may have a highly positive effect on the eutrophication. Models have been developed to evaluate the phosphorus retention of pre-impoundments (Uhlmann and Benndorf 1976 and 1980) and independent data supports the model excellently (Wilhelmus et al 1978).

The presence of humic substances in lake water may have a pronounced effect on the eutrophication due to a significant change in the extinction coefficient of the water. Humic substances are natural, coloured organic matter, but also man induced changes may alter the extinction coefficient, particularly pollution from paper mills.

Table 7.6
Classification of ecotechnological methods for lake restoration according to factor controlled

Factor	In lake	Change input/output
Light	Plastic beads, sheets, dyes or soot, circulation	Shading the shores
Soluble inorganic nutrient	Removal of sediment algae or P. Precipitation of P in water, NO_3^- to sediment	Pre-impoundment, wetlands. Precipitation of P in inflow, siphon of hypolimnion water
Soluble inorganic carbon	Change of pH	
Settling rate	Precipitation	
Retention time		Reduction of retention time
Grazing rate	Biomanipulation	

However, change of the extinction coefficient has also been used to depress phytoplankton growth (Jørgensen 1980 and Los et al. 1982). Hartman and Kudrilicka (1980) have studied the use of yellow tetrazin and found that 1 mg/l was needed to increase the extinction coefficient 0.08. Although yellow tetrazin may be harmless, it is not considered a sound ecological method to add artificial compounds to lake water. Other possibilities are shading of shores by trees or floating vegetation. The use of plastic non-transparent sheets, plastic beeds or soot have been tried rather successfully for small reservoirs and tanks.

Table 7.7
Effects on eutrophication of aeration as function of lake depth

Depth (meter)	% reduction in eutrophication
2-3	0-5
5-7	10-20
10	45-50
> 10	> 50

Biomanipulation has been studied quite intensely during recent years (Habacek et al 1978). The idea is to increase grazing on phytoplankton but it is still not clear whether the method can be used solely or it can only be used to bring the ecosystem faster to a new steady state after the forcing function have been changed.

It is hardly possible to give any general directions on which combination of environmental technology and ecotechnology to use to solve a given pollution problem of a lake. It requires the development of a model in each case to be able to take into account the ecosystem,the problem, the environment and the pollution sources. It is, however, possible to give some first directions based upon mass balance considerations.

Fig. 7.4 illustrates the possibilities which ecotechnology can offer by using of the mass balances. Firstly, a typical situation is shown for the phosphorus and nitrogen balance of many shallow lakes. This mass balance makes it clear that the highest reduction in the phosphorus input is obtained by treatment of the waste water. Then is shown a mass balance shortly after the discharge of waste water to the lake has ceased. It is here shown that the internal load is pronounced in the first time after the waste water was cut off due to the accumulation of phosphorus in the sediment - compare also with Figure 7.l. Finally is shown the mass balance after the lake has reached a new balance. In addition to the waste water cut off, is a wetland created in front of the main tributary for removal of nitrogen and phosphorus. It is presumed that the wetland is harvested at the time, when the phosphorus and nitrogen concentration of the phragmites are at the maximum. It is seen by comparison of the three mass balances that the very pronounced reduction in the eutrophication level is only obtained by application of the described combination of environmental technology and ecotechnology.

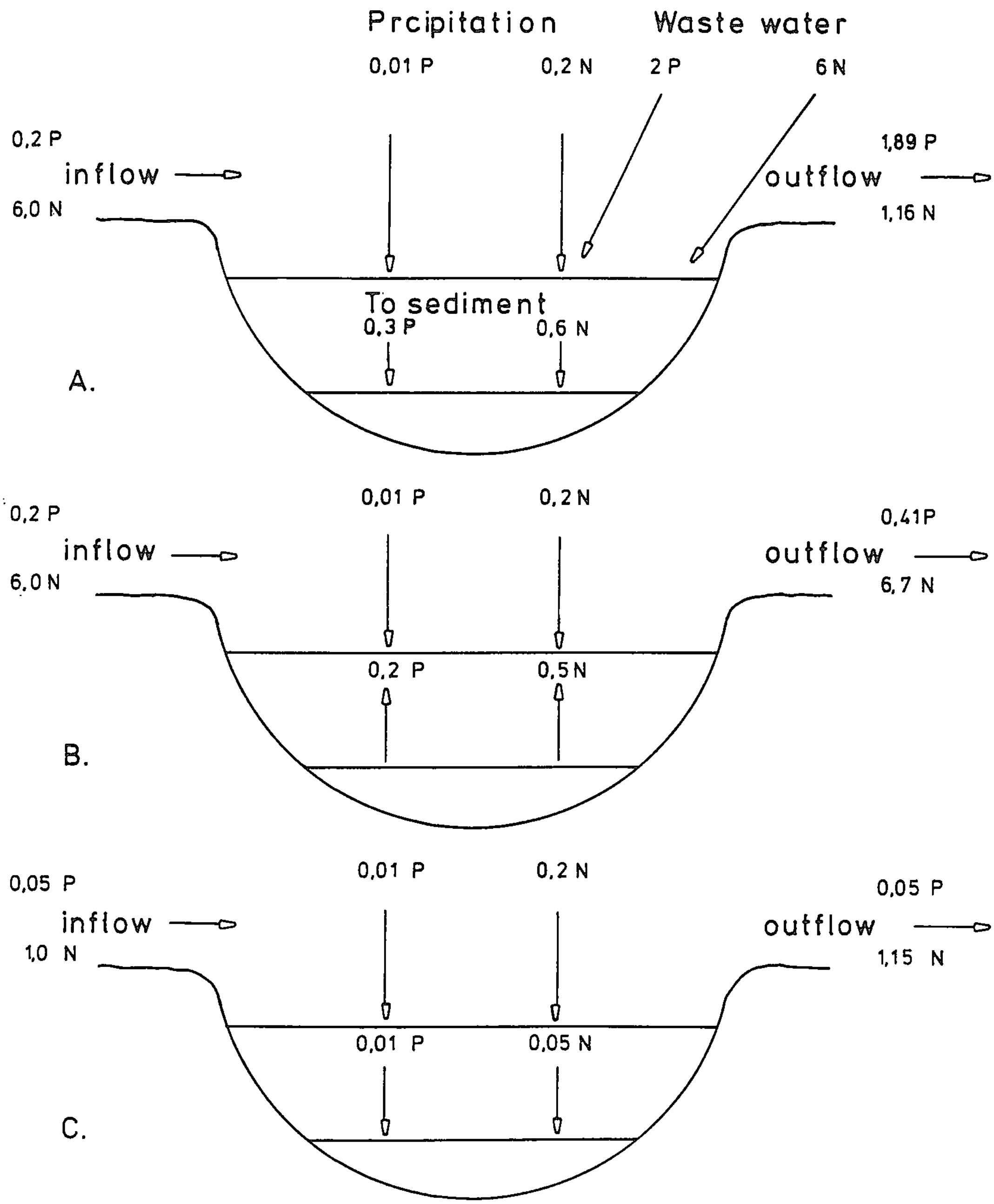

Figure 7.4 Nutrient budgets for a typical shallow lake a) with waste water inflow b) after waste water discharge has ceased c) some years later after a new steady state has been reached and a wetland has been constructed to cope with agricultural run off. The lake (20 ha, 5 m deep) has a retention time of 1 y and a catchment area of 10 km^2. All figures are 1000 kg/y.

The three levels are indicated in Fig. 7.5 on a Vollenweider plot and this graph clearly illustrates that the treatment or cut off of the waste water is insufficient and that additional methods should be considered. If the retention time of the lake is relatively long and it is considered of importance to get the lake in the new balance as quickly as possible further use of ecological engineering should be considered. As seen in Fig. 7.4 b the internal load coming from the sediment is significant and a removal of the upperlayer of sediment, discharge of drinking water to reduce the retention time or coverage of the sediment could be considered. If the lake has thermocline, it could also be considered to use the hypolimnion water as output from the lake to get a faster removal of the phosphorus and nitrogen from the lake.

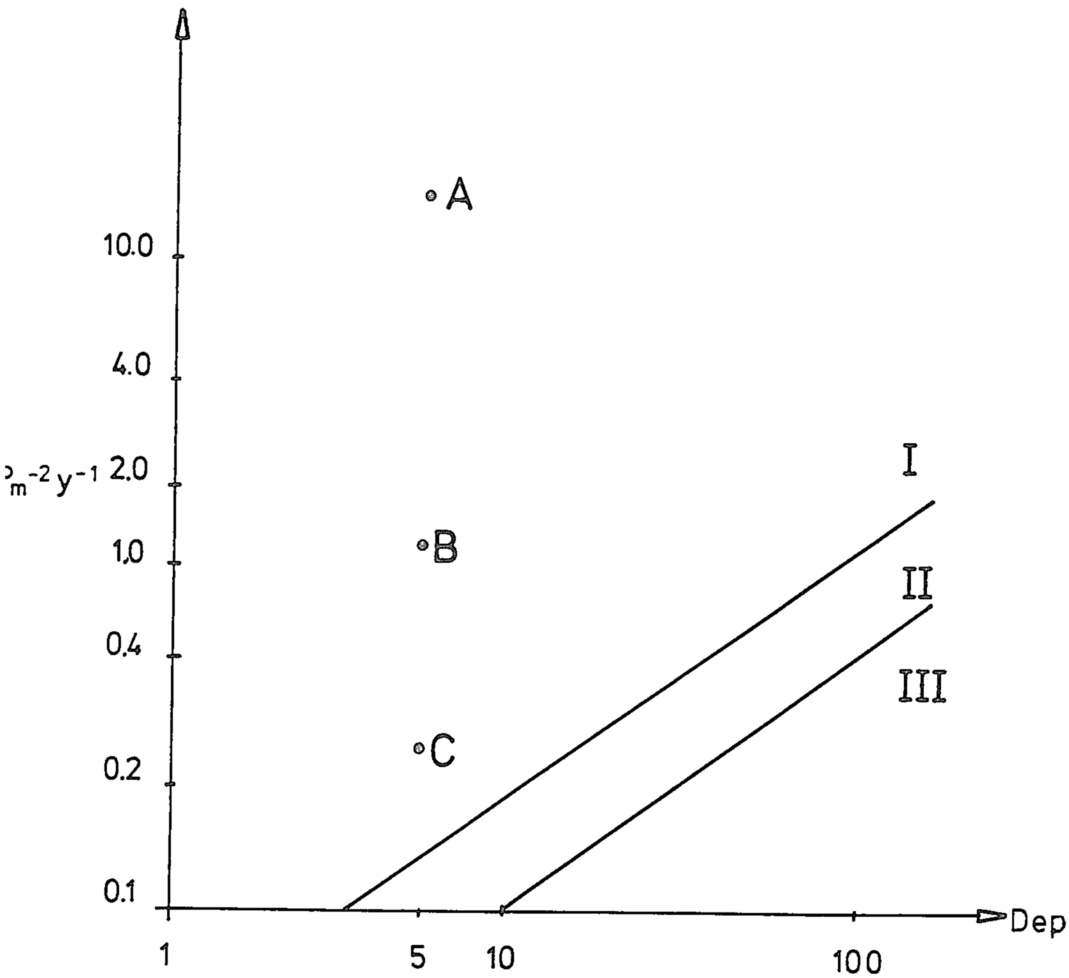

Figure 7.5 Vollenweider plot with data points corresponding to Fig. 7.4. I is eutrophic lakes, II is mesotrophic lakes, III is oligotrophic lakes.

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CHAPTER 8

PLANNING FOR SOUND MANAGEMENT OF LAKE ENVIRONMENTS

8.1 INTRODUCTION

Planning for sound management of lake environments requires integration of scientific knowledges into policies and programmes developed at all levels of decision-making. On one hand scientific information must be collected, collated, evaluated and used for developing practical strategies through on-site study programmes. Many of the basic principles described in earlier chapters will have to be properly integrated into the design of a good study programme. On the other hand, a long-term and comprehensive plan will also have to be developed at the highest level of administration in charge of lake management so that necessary resources could be mobilized to priority activities which collectively contribute to the sound management of lake environments. Since environmental problems are primarily local and regional issues, the environmentally sound management of inland waters, particularly of lakes, requires practical approach in terms of policies, administration and operations in given national, regional and local situations. This chapter deals with these and other aspects of planning for sound management of lake environments.

By way of introduction to the intricacy of planning for sound management of lake environments, a comprehensive international project of inland water management entitled EMINWA, together with institutional mechanisms and procedures required for its successful implementation, will be briefly introduced below.

The Environmental Sound Management of Inland Waters (EMINWA Project)

The traditional water pollution control approach of engineering orientation at the source of effluent has been challenged by the complex mechanisms of water pollution in the lake environment. The Environmentally Sound Management of Inland Waters Programme (EMINWA) was conceived by UNEP jointly with WHO, UNESCO and WMO in 1985. Within the umbrella of EMINWA, the Environmentally Sound Management of Lake Environments Programme was initiated with approval of the Governing Council of UNEP in 1987.

EMINWA is stated in the programme document by UNEP as follows: The environmentally sound management of inland(fresh) waters (surface-water and ground water bodies, e.g. rivers, lakes, reservoirs, streams, aquifers, large man-made water projects and their systems) is regarded as **an activity designated to integrate environmental concerns into the management of water resources.** By doing so, it contributes to on-going harmonization among the various interests involved in water-related socio-economic development and the natural environment throughout an entire inland water basin (hereafter referred to as river basin). It thus promotes **sustainable development** in the river basin.

The implementation of environmentally sound management of water resources in a river basin is a long-term activity which should be fit into the integrated river basin development process.

It should be applied to individual projects as well as at the **basin-wide level** and shoul take into account the co-existing functions (natural resource and ecosystem landscape foundations) of inland waters. It should promote the environmental management of surface water, inland, energy, and biota in terms of quantity and quality.

It would incorporate environmental considerations into a wide variety of water management and development activities connected with water and water-related projects within a water system. Activities would range from **assessment, monitoring, policymaking, planning and analysis of decisions through design and construction, to operation, maintenance and rehabilitation.** It would encourage the practical application of the principles of environmentally sound development of water management.

The EMINWA programme extends the scope of environmental planning and management beyond the traditional scope of jurisdiction of environmental administration. No single almighty administrative authority would exist. Planning and management would be carried out by a multi-jurisdictional administration whose goal would be the **integration between environmental conservation and social and economic development related to three terrestrial elements, namely the water body, shorelines and their inner and outer watershed of lake environment.** The effective institutional mechanisms and procedures should be established to comply with the objectives of EMINWA at local, regional and national levels, and even the international level in international river basins. The outline of the EMINWA concept is shown in Fig. 8.1.

Institutional Mechanisms and Procedures

A wide scope and integrated approach of EMINWA programme, together with appropriate **orientation** of an environmental approach within the

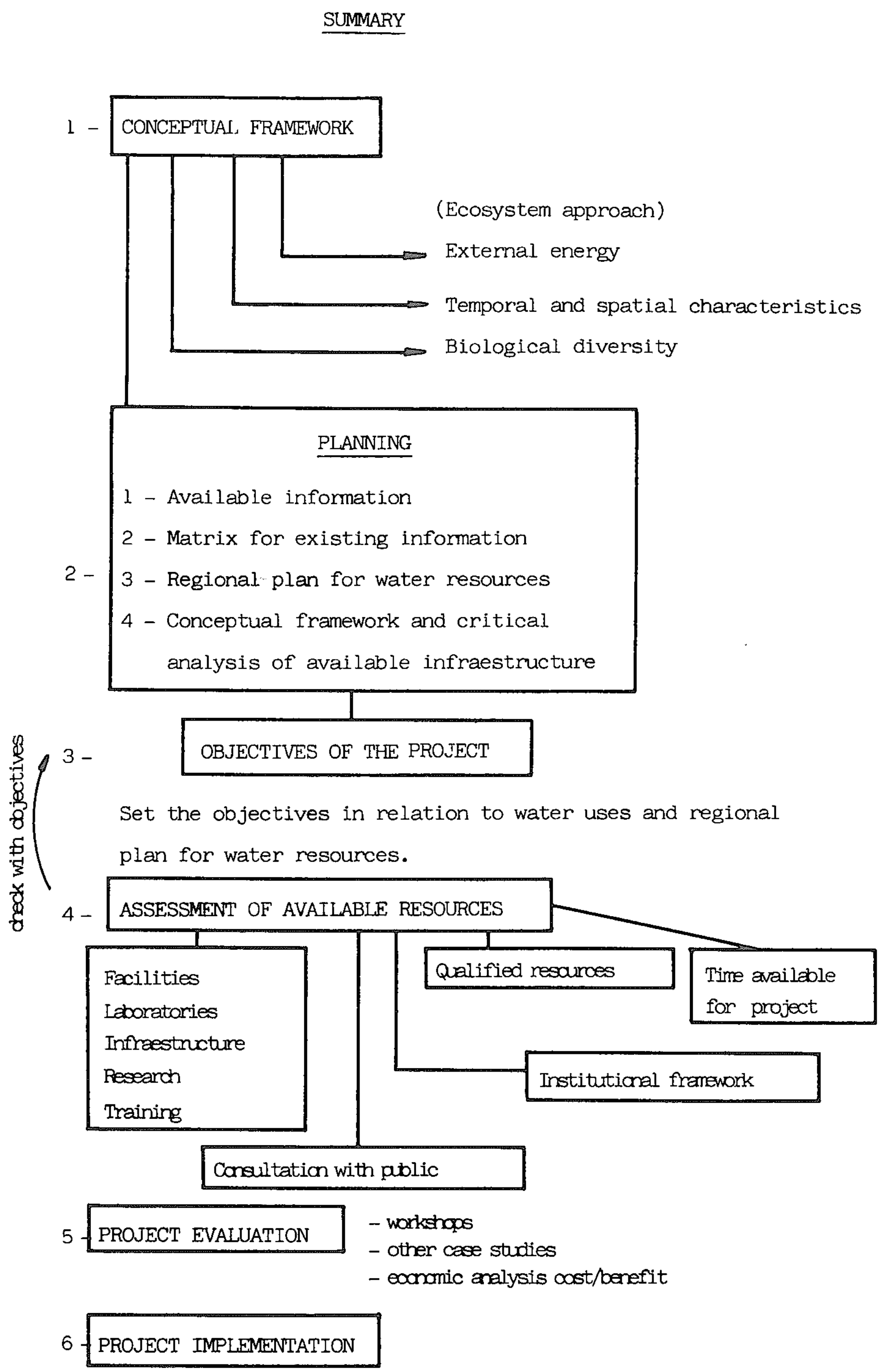


Figure 8.1: The summary of a project flow chart.

institutional mechanisms and procedures are essential for the environmental administrator.

There are three dimensions of interface in planning and management:

I Environmental components/socio-economic activities/government

II Government/public & private organizations

III Environmental authority/others/agencies including planning agencies within a government.

The term "**environmental components**" refers to the water body, soil (shoreline and the inner and outer watershed), flora and fauna in the lake environment.

The term "**social and economic activities**" refers to agriculture, forestry, fisheries, mining, manufacturing, power generation, construction, transportation, tourism and trade, and aspects of the population's behavior which bear significant potential for environmental impact in terms of the quality and quantity of lake water.

The term "**government**", refers to ministries and departments of various jurisdictions, and also stratification of national/local or federal/state governments based on the Constitution. Environmental components and related socioeconomic activities and their relationships with complex jurisdictional structures as well as traditional policy interests reflect the complex patters and processes in negotiation, coordination and integration within a government.

Inter- and intra-government relations are strongly influenced by public opinions and "**pressure groups**" of private organizations linked with various political interests at national and local levels. In the case of the international Lake environment, diplomatic issues may be involved in planning and management.

Within the government, there is a supreme legal instrument (constitution, laws, statutes, etc.) which provides a universal framework and order for powers, responsibilities, functions and activities of government organizations. Those are the products of legislagtion by the Congress. Then there is a **superior decision level** that establishes objectives and basic policies and orders, and co-ordinates and integrates among government actions under diversified jurisdictions. This is in the hands of the Cabinet or the Governing Council of the Executive branch of the State.

Under the direction of the superior decision level is a management level which is responsible for planning implementation according to the stated objectives and policies. The management level determines which strategies and supportive instruments will be used. The management level is further stratisfied into national, regional and local levels and differentiated into divisions of source control, environmental monitoring, infra-structure development, etc. Developing infra-structure divisions responsible for daily routine administration and technical operation in the field both at regional and local levels is a fundamental challenge of environmental planning and management.

Environmentally sound management of the lake environment involves a complex range of different types of decision-making. Firstly, the legislative policy decision must be made to provide necessary institutional mechanisms for integration between development and environment at the planning stage.

Secondly, the administrative policy decision must be made at superior levels on occasions of national development planning, environmental impact assessment, enforcement programmes, conservation measures and cost bearing for environmental measures. While the implication of the legislative policy decision is essential, the implication of the administrative policy is more substantive. They are more crucial in dealing with the dynamic interfaces among environmental sciences, government administration and national and local politics in the management of lake environments.

8.2 GENERAL PRINCIPLES IN PLANNING AND MANAGEMENT OF LAKE ENVIRONMENTS

Planning is a tool or working methodologhy to improve the use of available resources to comply with certain objectives. It requires knowledge of the reality on which it operates, capacity to evaluate the expected outcome and the process through which it can be attained.

In defining the planning objectives, it is essential that problems to be solved are clearly identified and appropriately defined. The assessment of available resources is indispensable for examining feasibility of undertaking a project. It also provides the rational criteria for allocation of resources based on a given set of priorities of plans, projects and programmes. Appropriate options, with criteria for selection and the expected outcome and probable consequences, should be presented for a sensible policy planning decision. Since a certain extent of uncertainty is unavoidable in any planning, a reasonable procedure for public involvement should be instituted when appropriate.

Management is a continuous, permanent, everyday work of keping assigned matters in the best condition based on the mandate within the established jurisdiction. Management is the link between the upper policy-making level and the operational team in the field. Management performs the following functions: provision of directions for implementation of plans, projects and programmes; organization and recruitment of necessary staff; negotiation and coordination with other relevant organizations; supervision and government of on-going activities; provision of consultation and guidance to staff; formulation of a budget and provision of the necessary materials; development of recording, reporting and data systems for rational management practice; establishment of a man-power development programme through training, education and job placement of staff; undertaking of public information services to promote understanding, support and co-operation, and if possible, appropriate public participation; and evaluation of the achievements of assigned activities.

Planning and management are continuous institutional processes. It is important to recognize that planning and management are real-world undertakings with certain constraints, and must therefore be operational and efficient. Plans must comply with their objectives and be executed within their scheduled time. The effective distribution of information and active efforts of communication between decision-makers, managers and operational staff, and interested organizations and the public are necessary for successful achievement of management objectives.

8.3 LAKE ENVIRONMENT DYNAMICS

Activity Subsystems with a Catchment Area

Planning and management of a lake environment may be described in terms of three constituent activity subsystems within a catchment area. These are (1) natural environmental systems of the water body and catchment area, (2) quasi-natural environment systems of forestry, agriculture and fishery as primary industrial activities, and (3) the population and its socio-economic activity centres.

The first encompasses a geographic area and constitutes a hydrological unit covered by a variety of ecological systems. These environmental systems support the second and the third. The multipurpose uses of the environment by the second and the third often results in conflict, because complex burdens are laid on the environmental systems. Natural water body and catchment areas cover a unit area irrespective of man-made boundaries between territories and legal jurisdictions of development and growth, which contribute further to environmental burdens. And the institutional gaps attributed to boundaries and jurisdictions often result in barriers to comprehensive environmental planning and management in the real world.

Lake Environmental Dynamics

The schematic diagram presented in Table 8.1 represents typical component activities and their dynamics with the lake environments.

Table 8.1
Compositions and dynamics of the lake environment (UNEP, 1987)

Catchment area and human activities	Probable adverse environmental consequences	Integration of environmental considerations into developement
Human settlement Public effluent Source Mining & manufact- uring industry	Environmental Burden of population	Development orders Infrastructure Development Housing sanitation Public & community efforts
Electric power Station Business, Tourism	Point Source of pollution	Industrial pollution control Effluent Wastes Discharge Products Processes
Transportation	Navigation	Accident control
Construction Work	Irreversible Alternation of the state of the Environment	Engineering Design Land use, Site, Route, Design, Technology, Operation
Agriculture Forestry Fishery Wildlife reserve, Natural park	Non-point Source of pollution Degradation of natural environ- mental resources	Sustainable agriculture, Forestry, Fishery, Pesticides, Fertilizers Regulation, Management of soil, Irrigation water use, River, Flood Plain & Mountain
Natural Background (Native) transbound- ary pollution	Disruption of Life support Environmental Systems	Nature conservation Wildlife protection, Historic, cultural heritage protection Flood/drought control

The water body of a lake is the sum total of the water which comes directly from the lake catchment area and indirectly from subcatchment areas of tributary rivers which flow into the lake. All of these are integral parts of the natural water cycle (e.g. precipitation, surface run-off, infiltration, percolation and groundwater flow). Soil-water interrelations modified by flora and fauna and precipitation influenced by air transport of substances constitute the input and output balance of waters. Environmental burdens are generated through population settlement due to emissions of waters from mining, factories including public sewerage facilities and waste-water treatment plants. The chemicals contained in pesticides and fertilizers used in agriculture and forestry are the burdens of non-point sources. Geochemical elements from mining, and agricultural and animals wastes are other non-point sources. Soil erosion is caused by natural and quasi-natural phenomena of river beds, and dam and lake beds. If the soil erosion is unappropriately controlled, the water pollution in lakes progresses, flood risk increases, dam life is shortened and the future utilization of water is endangered. Underground leakage of toxic chemicals from waste dump sites could have serious environmental impacts. In the 1970's pollution sources of the Great Lakes in North America, toxic chemicals and/or heavy metals deposits attributed to chemical wastes, as well as mining wastes contained in bottom sediments constituted distressing "stock pollution" problems.

The Minamata disease in Japan was caused by biological condensation in fish and shellfish of alkylemercury discharged in industrial effluent of the acetaldehyde manufacturing process which uses an inorganic mercury catalyzer. A heavy oil pollution accident in Lake Maracaibo in Venezuela caused by an oil spill, and the massive loss of human life due to a burst of CO_2 from the bottom of Lake Nias in Cameroon caused by volcanic action are to be remembered as serious experiences of lake disasters.

A river is a flow of water, but a lake is a stock of water. Owing to the long water replenishment time, lakes cannot clean themselves as rapidly as rivers. The stock of nutrients, persistent chemicals and heavy metals deposited in the bottom sediments are difficult to flush out because of the long water replenishment time. Furthermore, the weight of pollution from non-point sources hampers the effectiveness of the traditional water pollution control approach by means of engineering control at the source. Meanwhile the ecosystems of lakes are highly sensitive to changes in their drainage basins. Disruption of the relationship between soil and water at outer and inner watershed of shoreline results in irreversible impairment, sometimes resulting in total destruction of the ecosystems of marshes and wetlands which are indispensable as habitats for wildlife and fisheries. An ecological approach, with due consideration to complex and delicate environmental systems as interactions among soil, water and biosphere, is essential for lake environment conservation.

Need for Special Considerations to Water Resource Development Activities

Fresh water from lakes (natural and man-made) is an essential but scarcely renewable natural resource which supports life and promotes socio-economic development. Surface water is used in extractive and non-extractive ways. Uses such as human consumption, domestic and wild animal consumption, aquaculture, irrigation, operational use at public and private places, electric power generation, mining and industrial uses, artificial aquiferous re-charge, etc. are extractive uses. Uses as a life medium for aquatic ecosystems, fishing and fish culture, hydro-electric production, navigation and transportation, reception of effluent discharge, swimming, recreation and sight-seeing, etc. are non-extractive uses. There is a wide variety of requirements and demand/supply conditions in terms of quantity, quality, location, timing and means among those multiple uses.

Environmental management is important for all modifications made to water basin, but especially important in construction works that directly modify the water flow by retaining or diverting it (frontal dams, lateral dams, water gates, tunnels, aqueducts, channels, etc.). Dams and their impoundments, reservoirs and artificial lakes in particular, produce or lead to drastic modifications of the water regime and aquatic and land ecosystems (which disappear in flood areas) and can produce a substantial modification in the functioning and configuration of the original water system. Careful planning and integrated interdisciplinary analysis of cost and of irreversible environmental impacts is essential. Environmental Impact Analysis (EIA) is institutionally required prior to the approval of a master plan. For major works, the impact must be analyzed in three stages (construction, filling of impounding, reservoir completed), and for different sub-regions of the basin: upstream location area (impounded area), and down stream. After a dam is built and the analysis of the evolution of its multiple impacts carried out, other important aspects of environmental management appear: evolution of reservoir water quality, dam management and spill regime (which will be related to the preparation of the impoundment before fillings as well as the activity developed in the basin upstream).

An increase of endemic diseases often accompanies the creation of large reservoirs. Factors of "vector ecology" related to possible endemic diseases demand special attention from environmental planners and managers. The propagation of schistosomiasis and the northerly migration of malaria mosquito vectors from Sudan are reported as examples of such a case stemming from the Aswan High Dam project. High morbidities of epidemic and endemic diseases related to water are one of the important public health problems in the Common Zambezi River System.

In de-salinization of brackish lakes for agricultural irrigation, the salt content of lake water dictates the trade-off between agriculture and fisheries. Japanese experience in Kasumigaura Lake and the on-going controversy in Nakanoumi Lake are typical examples of the anticipated impacts. Both cases are connected to sea through tidal estuaries, where a salination barrier is constructed. The simulated operational conditions have proven a decrease in the salinity of the irrigation water which may, however, be adverse to the existing fishery.

Where nature ecosystems for wildlife exist, land reclamation projects along coastal areas of lakes will change the water front environment in an irreversibel manner. J.A. Dixon presents the loss of economic development opportunities by multi-purpose dam projects as follows:

a. Valley dwellers displaced upland or to the flood plain below the dam. Wildlife habitat is destroyed also.
b. Migrants add to population pressure on marginal and steep sloping lands resulting in increased soil erosion.
c. Upland activities (farming, forestry, agro-forestry, roads and settlements) causes soil erosion, silt and chemical pollution of streams. Sediment is stored in delivery system awaiting storm events.
d. Sediment from eroded soil is deposited in reservoir and reduces storage capacity.
e. Turbidity affects fisheries and recreation.
f. Nutrient flow causes eutrophication and aquatic weed problems.
g. Irrigation leads to increased loading of silt into the water requiring dredging canals.
h. Salinization and water logging of soil may occur from improper irrigation.
i. Irrigation return flows to river may carry toxic chemicals and salts which affect downstream fisheries and other water uses.

It is important to stress the fact that each water basin and each dam is a unique case. In particularly, the differences between characteristics of lake environments in the temperate zone and the tropical zone need to be carefully recognized because of a relative scarcity of data and information of tropical lake environments.

8.4 PLANNING AN ON-SITE STUDY PROJECT

With all these contributing factors to lake environment dynamics, it is of great importance to establish the interrelations among these factors through a well designed on-site study project with scientific tools of analysis.

Defining the System

The establishment of a good on-site study project for lake management requires, as stated in earlier chapters, an ecosystem concept and application of system principles to planning. The ecosystem is a dynamic system, and it possesses some invariant properties. The changes in the ecosystem may be slow but its component species and communities goes through a process of succession and fluctuations and this can be very fast. Short term dynamics in aquatic ecosystems is thus a very important characteristic to be recognized and introduced in the planning procedure. Human activities interfere with the energy transfer and as a result, cause disturbance to the ecosystem such as species alteration. The system in this case is the watershed since several inputs and processes important for lake management are commencing on the watershed.

The following major properties of the system and its functioning should be considered in the planning:

1. Sources of external energy and inputs (such as wind and runoff in lakes and reservoirs)
2. Temporal and spatial characteristics of the ecosystem, its variability, its boundaries, scales and possible impacts. Time scales of the changes
3. Diversity of the ecosystem (biological diversity) and main connections among its components.

Initiating a Study

The following steps should be taken for initiating an on-site study project.

The first step is to define the system (watershed) and to obtain and analyze the existing information. The following data should be obtained at this stage:

a. Latitude, longitude, altitude, climate
b. Morphometric relationships in the watershed: lake area, basin area, river drainage system, geomorphological background (see also section 2.7)
c. Soil types, soil uses, vegetation (see also section 2.3)
d. Human activities in the watershed including history of occupation and traditional water uses (see also chapter 1)
e. Main mechanisms of lake functioning: forcing functions, state variables, processes, and if available, long term data (see also section 2.4).
f. Information on the biological component (diversity, productivity, interactions (see also section 2.3).

Thus relationships between the main components of a system can then be established, and a conceptual model can be proposed.

The critical analysis of the existing information is an important process. It will give an idea of the deficiencies in information required. In many developing countries the data are scattered in many different sources and may not be readily available. This attempt for information should therefore give a clear idea of the current state of knowledge about the ecosystem.

This <u>second step</u> in the planning has to take into account the following:

g. The available information and the diagnosis of the conditions.
h. The regional development plan which includes the water uses in the framework of community needs and the required water quality.
i. The time schedule for the development of the project considering the water uses and quality.
j. Considerations on the monitoring and research approaches should be part of the objectives.
k. A training component should be set in connection with objectives.

<u>The third step</u> is to assess the available resources:

l. Existing facilities (laboratories, infrastructure) for monitoring, research and training.
m. Qualified staff with knowledge on the area, and training.
n. Examination of perspectives for project implementation against available information, facilities and infrastructure.

The examination of the available information, the existing facilities and infrastructure, together with the objectives will provide a basis for the project implementation and the level of activity. In the assessment of available resources a detailed knowledge is required of the financial resource allocation, including the needs for the continuity of the project and follow up actions.

Another important assessment is the institutional arrangements including the links with the international system of research and development. It is essential to understand the involvement of the various institutions concerned and the extent to which cooperative efforts can be exerted.

Planning and Evaluation of the Project

The project should consider the following activities at this stage:

1. Minimum information required for lake management including basic monitoring parameters and observations (level I).
2. Second level of information required for the management procedure. Monitoring and limited experimental research (level II).
3. Third level of information required: maximum use of human resources, infrastructure of laboratories and equipment. Monitoring and long term experimental research (level III).

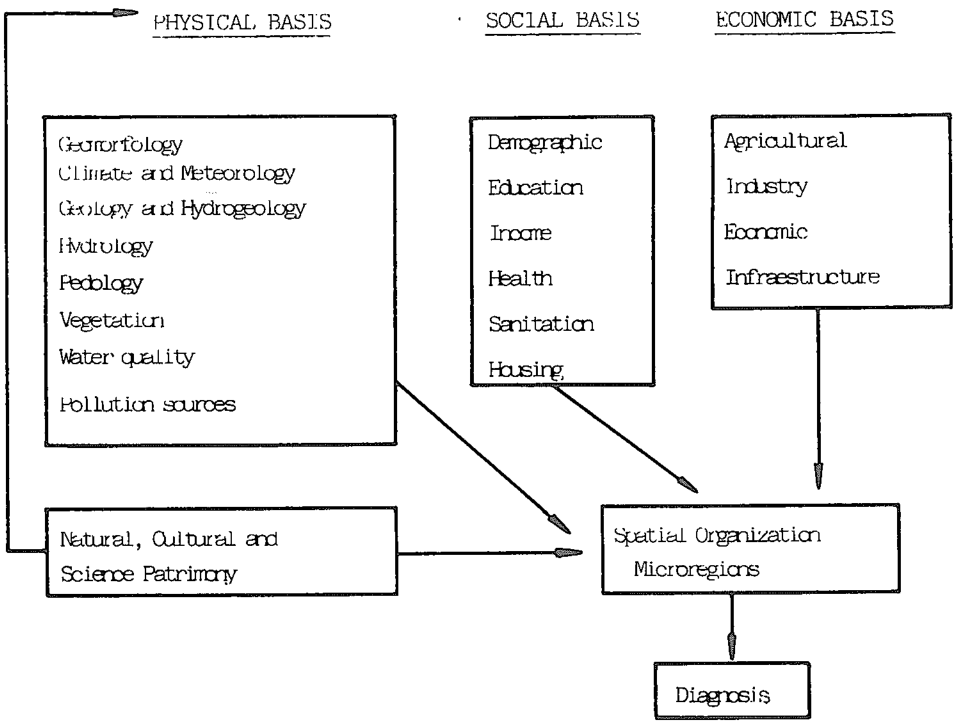
Training of human resources must be an important component. Different kinds of training should be adapted to the various stages of the project. This training would emphazise basic needs, techniques. It also provides a general knowledge of limnological research and its application to lake management. Training should be oriented in a regional context, to action, and to practice and improve management skills.

In a developing country efforts should be placed in the development of human resources in the first step and instruments in a later stage. It is important to establish different capability at different periods in the project plan. A combination of monitoring/research and training in the lake itself is another fundamental requirement of training.

Seminars and workshops with presentation of other case studies are very important for a critical analysis of the project.

Project Implementation

At this step it is necessary to organize the institutional framework and to verify the technical and socio-economic aspects of the project. The implementation of the project involves examination, improvement and provision of opportunity for developing working relationships between limnologists, managers and policymakers. While one or two groups are engaged in research and management, other groups should prepare the necessary legislation, and develop different measures to secure the strict following of the objectives of the project.



From HOLTTZ (ed.), 1986

Fig. 8.2: Planning of an On-site study project

Another aspect at this stage of the project is the involvement of the local community. Several problems in the implementation of the project for lake management could be solved with the participation of local community. The development of an adequate interface with the local community has been proposed by Tundisi (1986). The linkage between science, technology and public should be reinforced in the implementation of the project.

A good coordination of all the activities in a lake management project of should be emphasized. The establishment of a global network of institutions collaborating in the sharing of data and information is also important. The follow-up actions should also include examination of contingency measures in case of project failures. The community participation at this stage is also fundamental.

A summary of the entire process of planning of an on-site study project is presented in Fig. 8.2.

8.5 EIA AS AN INSTRUMENT FOR INTEGRATION OF ENVIRONMENTAL CONSIDERATIONS INTO DEVELOPMENT PLANNING

The environmentally sound management of lake environments requires comprehensive planning together with a well-designed on-site study programme as described in section 8.4. The mode in which individual component programmes within a given comprehensive plan get implemented depends much on the existing institutional as well as legal frameworks. Mobilization of the necessary resources to activities of priority concern is prerequisite to successful implementation of projects.

While much depends on the design of a comprehensive plan for sound management of lake environments, there is another important subject requiring special treatment, i.e., Environmental Impact Assessment (EIA) as an important part of the environmentally sound management of lakes and other inland waters.

EIA is a basic and essential policy instrument for incorporation of environmental considerations into the planning and implementation processes of development to achieve sensible integration of environment and development. EIA involves a scientific, inter-disciplinary approach, but it is important to note that science is but a tool to be used for appropriate, rational policy decision. EIA is an issue for real world practice in administrative and political processes. It is to be organized as a reasonable, systematic, effective, efficient and fair process within certain constraints of cost, man-power, scientific and technical feasibility and time schedules.

A legislative base for those processes and procedures is indispensable, and the support at the decision level of government is indispensable to effectively implement EIA.

In principle any development organization, whether public or private, should be responsible for conducting EIA when planning or implementing a project or programme with potential of significant environmental impact.

The EIA report should comply with the basic objectives of EIA, which are:

a. **Identification of potential quantitative and qualitative environmental changes** that would be attributed to development activities.

b. **The criteria for evaluation** are to be based on both optimistic and pessimistic scenarious to facilitate appropriate judgement of expected risks and benefits of the development project or programme.

c. **Incorporation of environmental considerations** into development planning, implementations and actions by means of appropriate mitigating measures in terms of land use, siting, routing, layout, architectural designs, engineering technologies for control and/or construction from the earliest stages of development.

d. **Examination and recommendation for alternatives** if necessary.

e. **Identification of the critical environmental problems** which require further study or follow-up through systematic monitoring after approval of the application (e.g. disruption of crucial environmental systems of the lake environment and associated long term effects).

f. **Participation of a well-informed public** through appropriate public procedures to facilitate a sensible decision-making process.

g. **Integration of the concerns of the environment and development for achievement of sustainable development** through mutual understanding and cooperative efforts among all parties involved.

When carrying out EIA, the following **issues** are to be considered for their effects on the lake environment:

a. **Water resources** in terms of quantity and quality,

b. **Water input/output changes** in terms of quantity and quality,

c. **Change and Fluctuation of water level,**

d. **Physical changes of shoreline** including the inner and outer watershed,

e. **Vegetation** (especially forest) cover of the catchment area,

f. **Degradation of soil conditions** (erosion, salination, desertification, etc.),

g. **Siltation, sedimentation of water beds,**

h. **Habitation of wildlife** (fauna and flora),

i. **Irreversible changes** of the state of unique interests (historical, cultural, archeological, aesthetic, etc.),

j. **Urbanization and industrialization** with significant environmental burdens in terms of environmental pollution,

k. **Changes in water and land use** having significant implications on the catchment area and water body,

l. **Area of particular social interest** to a specific vulnerable population (traditional livelihood and life-style, etc.),

m. **Resettlement of population.**

Projects or programmes most in need of EIA are as follows:

a. **Exploitation of hydraulic resources** (e.g. dams, irrigation and drainage projects, water supply, water and basin management project for multipurpose development and allocation, weir operation, salination barriers),

b. **Industrial activities** (e.g. smelter, iron & steel, pulp & paper, refinery and petrochemical, chemicals, electric power, cement industries, etc.),

c. **Extractive industries** (mining, oil drilling, quarrying, peat, gas, etc.),

d. **Waste management and disposal** (e.g. excreta, waste, refuse, dumping, land-fill, sewerage treatment plants, treatment plants for urban and industrial wastes, particularly hazardous wastes, etc.),

e. **Substantial changes in farming and fishing** (large scale mechanization of agriculture, fishing, introduction of new species, extensive use of pesticides and fertilizers, large scale cattle farming, range development, etc.),

f. **Coastal development, resort development, land reclamation**,

g. **Infrastructure development** (e.g. roads, bridges, airports, harbors, pipe-lines, transmission lines, railways, etc.),

h. **Substantial changes in uses of renewable resources** (large scale logging, conversion of land use from forest to agriculture or pasture, agricultural land reform, etc.).

In addition to projects and programmes, those changes of lifestyle and consumer products among the population which generate significant impacts through wastes, refuse and domestic effluent should be considered. The massive consumption of non-degradable synthetic detergents and their phosphate contents are typical examples.

EIA Implementation

EIA in a broad sense encompasses those excercises stated above which are universally required for all development projects and programmes. This is particularly true in developing countries where feasibility of EIA is more severely constrained. Organization, schedules, methodologies used, available resources of professional man-power and scientific and technical infrastructures and cost are the crucial issues for implementation.

a. **Organization**: The scope of work and mandate are to be clearly defined for the EIA interdisciplinary team. Time schedule and available resources should be well understood before beginning of EIA. The EIA project leader should be carefully chosen from the standpoint of role orientation of each of the disciplines and interfaces involved in the interdisciplinary approach. Management capability is also required. All findings and conclusions of excercise stated above should be provided to the EIA team.

b. **Methodology**: Lohani and Halim (1987) examined the most commonly used methodologies and recommended methodologies for rapid EIA in developing countries. However, it is important to note that no single method can provide satisfactory answers for EIA. Each of those methodologies have usefulness and liminations or weaknesses. From the standpoint of the ecological approach to EIA in the lake environment, it is essential that an interdisciplinary expert team together with local people interested in environmental issues through indigenous life experience conduct field reconnaisance. Because of conflicting interests concerning land and water use between upstream and downstream communities Trans-boundary issues among different jurisdictions within the catchment area as well as those affecting jurisdictions outside of the catchment area are important. Also indispensable are flora and fauna which constitute most fundamental environmental support systems for sustaining human populations. Since construction works resulting to modern engineering technology often result in unreasonable environmental destruction, sensible design of engineering operation at the sites of important ecological values should be deviced through reasonable techno-economic appraisal for attaining of acceptable ecological changes.

c. **Public Procedures**: Public announcement of an outline of the development project or programme at an early stage, public disclosure of environmental impact statement (EIS) based on the EIA report, and public relations programmes of the development plan with EIA findings and conclusion, and if possible, public hearing sessions are the most common public procedures in prevailing legislation. Those programmes are essential for promotion of public participation. A well informed public is a prerequisite for fair and balanced policy decision in EIA.

d. **Cost and Time for EIA**: These are associated with various practical factors for implementation of EIA. Meteorological and hydrological aspects, require in principle a considerable period of monitoring. Data reflecting as much seasonal variation as possible should be included. The monograph of "EIA in Developing Countries" said that the cost of EIA in developing countries varies from 0.1% to 0.5% of total project or programme cost. The OECD Special Project Group on Environment Assessment and Development Aids said 0.01% to 1.1% of total project cost is spent for direct cost of EIA in developing countries. It is important to remember that prevention is cheaper than treatment.

8.6 CONCLUDING REMARKS

Environmental planning and management of lake environment is a typical issue of comprehensive regional management over a certain geographic area. It involves the concurrent interaction of factors that can be generically grouped in four sectors

1) **Science and technology** is a reference group that provides basic knowledge and skill for problem identification and solution,

2) **The government group including quasi-government corporations** in a wide range of jurisdictions provide an institutional approach to prevention, abatement and promotion,

3) **The industry group** contributes and participates through orderly industrial activities of production and development regardless of scale or industrial classification, and

4) **The public as individuals and groups** participate in lake conservation programmes through their daily life and livelihood activities. It is important to remember that each of the sectors has both positive and negative potentials for development and the environment in lake environment conservation efforts. Without sufficient mutual communication of information and education, an effectively organized approach cannot be expected.

Through studies, research and experimentation scientific background knowledge for problem solution is provided. Environmental monitoring is not only matter of sophisticated analytical techniques or instruments, but also a matter of careful, continuous observation and perception by the local eye. Different roles and potential for problem identification and solution should be carefully taken into account for planning and management of the lake environmental issues can be expressed both in positive and negative ways. Government expects positive patterns of understanding, co-operation and participation by means of public information and education approach. A well informed public is able to understand well and make knowledgable judgement to public. The identication of effective communication channel to public with special interest is important from a tactical viewpoint in occasion of public approach. It is important for government to have an appropriate understanding of the public to speak fairly. Understanding differences between perception and technological rational is essential for administrator and scientist. The role of the University as the institute for higher education and development of theory, principle, knowledge and skill within a wide spectrum of scientific disciplines, must assume the responsibility of organizing courses on environmental education for teachers and professors at different levels of education. It is also necessary to provide courses. This would provide an understanding and orientation of one discipline in the interdisciplinary approach to human environment issues. The interface among ecology, economy and engineering is the focus of educational need to be explored positively also through interdisciplinary curriculum in higher educationan institutions.

Also, a graduate course for professional education in environmental science of integration between environment and development at the community level is important.

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PART B

CASE STUDIES

Three cases studies from tropical regions have been selected to illustrate the considerations and principles of lake management.

Chapter 9 presents the case study of Laguna Lake close to Manila. This case study illustrates the ecological consequences of a significant antropogenic impact on a lake ecosystem and how difficult it is to solve pollution problems in an area of dense population and heavy industrial activity in a developing country.

Chapter 10 focuses on management of reservoirs in Brazil. Construction of dams in developing countries and their ecological implications are very important management problems. This chapter illustrates the importance of these problems and discusses how the problems could be solved.

Chapter 11 concerns the construction of a dam - Saguling Dam - in Indonesia. The paper presents mainly the sociol-economic consequences of the dam construction and indicates the importance of this part of the problem complex. Various approaches to the solution of these problems are presented and discussed.

Case studies, which would demonstrate the improvement of water quality in lakes, where the pollution impact has been reduced, could have been included in this part. A few such case studies are, however, described in detail in the literature and reference to these studies are given below. A very brief presentation of the most important experiences gained by these studies should be given here.

Lake Washington is maybe the most famous of these case studies. The study has demonstrated that the recovery of a lake will follow the relationship between the phosphorus loading and the eutrophication.

The results of modelling Lake Glumsø should however also be summarized here. This case study is unique, because a eutrophication model was developed and used to set up prognosis before the waste water diversion took place. A validation of the prognosis was therefore possible (see Jørgensen 1976 and Jørgensen et al 1986). A few important data from the prognosis should be mentioned to illustrate the predictions possibilities. The prognosis predicted that the transparancy at minimum would increase from 18 cm to 50 cm the third year. The observations showed 48 cm. The prognosis predicted similarly that the maximum chlorophyll concentration would decrease from about 800 µg/l to 320 µg/l the third year. The observations showed an improvement to 380 µg/l. This case study has demonstrated that it is possible to set up prognosis for the development of eutrophication by using models and that a significant recovery of a lake could be expected in accordance with a reduction in the nutrient loading.

CHAPTER 9

LAGUNA DE BAY REGION PHILIPPINES

9.1 LAGUNA DE BAY REGION AND PHILIPPINE DEVELOPMENT

The Laguna Lake Region nestles among the most urbanized chartered cities (Manila, Quezon, Pasay, Caloocan and San Pablo) as well as two of the richest provinces (Rizal and Laguna) of the Philippines. Parts of three provinces (Cavite, Quezon and Batangas) are found also within the lake's region.

The Laguna Bay Region covers 4945.4 km^2 of land. Its upstream catchment covers 404,540 hectares while the lake itself measures 90,000 hectares. The downstream area is 38,200 hectares. (See Fig. 9.1)

Laguna de Bay, being the Philippines' largest inland water body, plays a key role in the national economy. It is located near the country's capital region of Metro-Manila, the centre of government, business and education. In fact, most of Metro-Manila is located within the lake's basin or downstream area. Thus, a considerable proportion of the Philippine population resides within the lake basin area. Also, most of the country's industrial establishments are distributed within the Laguna Lake Region.

The proximity to the country's capital makes Laguna de Bay not only a major factor in economic development, but also a source of cultural inspiration and recreational amenities. The lake, its surrounding mountains and beautiful scenery are intimately woven into the cultural and historical fabric of the Philippines people.

FIGURE 1

LAGUNA DE BAY REGION

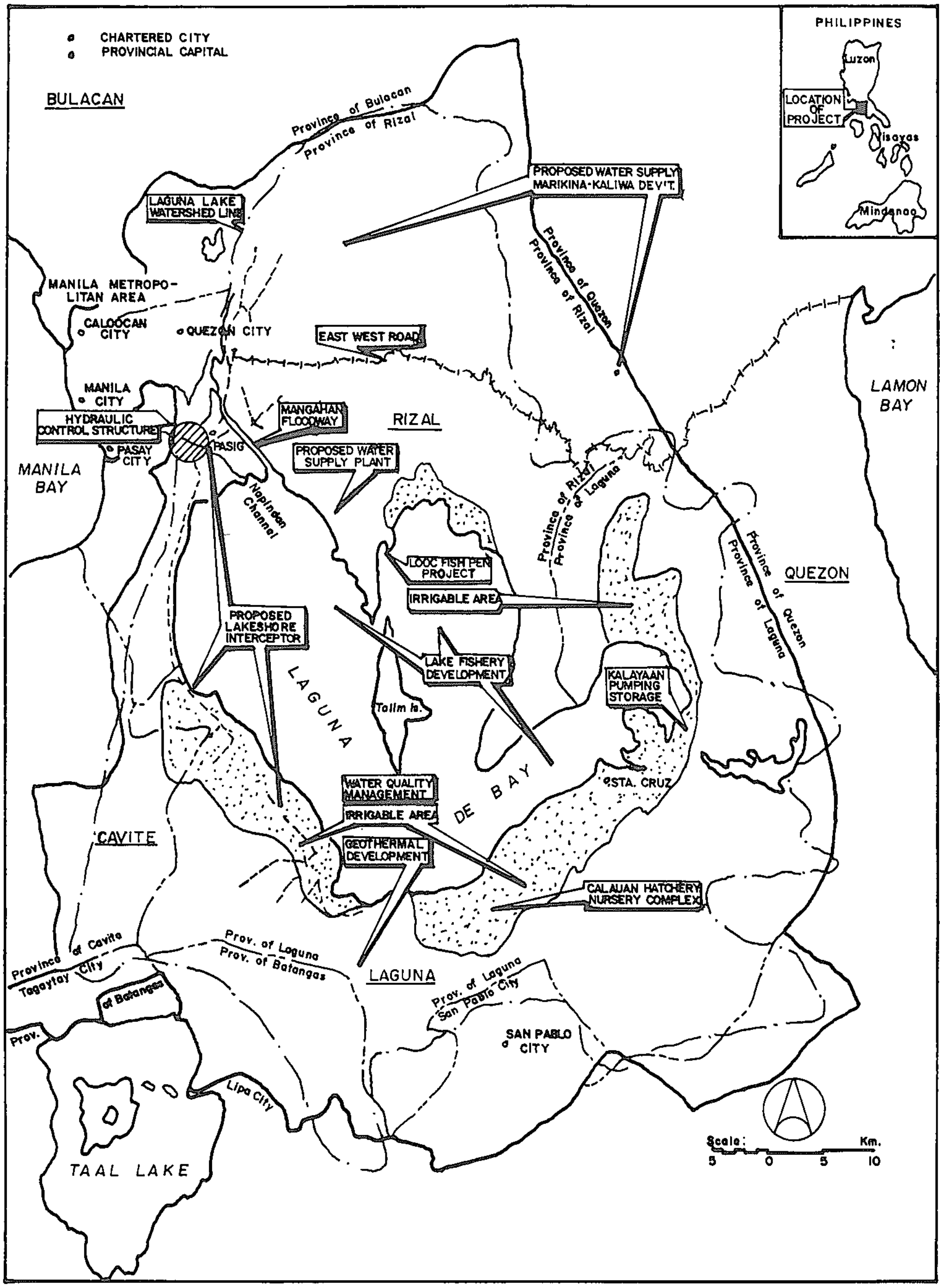

Figure 9.1

9.2 BIOPHYSICAL PROFILE OF LAGUNA DE BAY REGION

Catchment of Laguna de Bay

The catchment area of Laguna de Bay is bounded by the Sierra Madre range in the north, the Marikina watershed in the west, and by Mount Banahaw and Mount Makiling in the east and south, respectively. These mountains and associated hills provide the backdrop to the predominantly flat landscape of the region.

The westeren and notheren lakeshore areas are the most developed in terms of urbanization and industrialization. This is the location of Metropolitan Manila and the more prosperous towns of the provinces of Laguna and Rizal. The southern and eastern parts of the catchment are largely agricultural, punctuated by built-up areas such as the town of Santa Cruz, the capital of Laguna province, Pagsanjan a top recreational spot, and Los Banos, where the nation's main university for agriculture and forestry, as well as hot spring resorts and pristine tropical rainforest are located.

The total land area estimates of Laguna de Bay Region are varied. The latest available figure gives the area as 404,540 hectares representing about 1.3% of the Philippines (LLDA, 1984). The land use classification of the catchment area (ILEC, 1984) is summarized in Table 9.1.

Table 9.1
Land use in the Laguna de Bay catchment

Class	Area (km^2)	Area (%)
Agricultural land	1984.6	52.0
Woody vegetation	908.6	23.8
Herbaceous vegetation	617.0	16.2
Settlements	248.3	6.5
Swamp	25.3	0.7
Others	38.7	0.9
	3802.5	100.0

An urban-rural dichotomy is readily discernible in the Laguna de Bay Region, since the western half is characterized by urbanization and industrialization, while the eastern part consists dominantly of croplands (mainly coconuts, rice and some corn and sugarcane). Urban spread occurs mainly in the south, creeping from west to east. An industrial estate and several factories were established also in the south to accommodate entreprises affected by an industrial ban within a 50 km radius of Manila.

The large erosion-prone areas are located around the west border of Caliraya plateau, recent volcanoes in the southern region of the basin and the east border to the Marikina-Montalban Valley, as well as the Binangonan, Talim and Jala-jala areas in the north.

Demography

The population of the region (including Metro-Manila areas under LLDA jurisdiction) exceeded 6.2 million in 1980, with an annual growth rate (1975-80) of 3.7%. There were more than 1.1 million households with an average size of 4.8. Most of the inhabitants (70%) reside in Metro-Manila cities and towns found along the west shore of the lake. The rest of the population (30% of total) are scattered throughout the region. The highly urbanized population of Metro-Manila increased the gross population density to 1,524 persons per square kilometer, which is almost ten times the national average of 160.3 in 1980. The urban-to-rural population ration is 7.8 and still increasing.

Since the commercial, cultural, political and educational centres of the country are located in the Laguna de Bay region migration into the area is correspondingly very high. In 1980 almost 63% of total households in the lake region were immigrants, almost half of which came from far flung provinces. Also, the literacy rate is quite high at 94.7%.

Laguna de Bay

Hydrology of the lake

Laguna de Bay is the largest freshwater lake in Southeast Asia. Its mean depth is only 2.8 meters, with the deepest parts reaching to about 6 meters. The shallow lake is conventionally divided into three bays (fig. 9.?) by a peninsular and longitudinal island (Talim) jutting from the north-western coast, and further larger peninsula emanating from the north-eastern coast. Thus, the lake waters are named either West Bay, Central Bay or Eastern Bay. Some refer to a South Bay as well.

Some 35 tributaries drain into the lake, the major ones being (from the northwest clockwise to the norhteast):

Antipolo River
Napindan River/Pasig River
San Pedro River
Bay River
Santa Cruz River
Pagsanjan River

The only outlet from the lake is Pasig River on the west side which runs through the urban areas of Metro-Manila and discharges into Manila Bay. The water level of Manila Bay is only 1.0 metre lower than Laguna de Bay, thereby creating restrained water conveyance from Laguna de Bay. During the rainy season (May to December), flooding of lakeshore communities occur when precipitation exceeds 300 mm per month. However, when the tide is high during the dry season (January to April), Pasig River flows in reverse into Laguna de Bay. This back flow brings salinity from Manila Bay into the West Bay of the lake, as well as nutrients from domestic pollution and toxic substances from industrial pollution of Pasig River.

The construction of the Napindan Hydraulic Control Structure connecting Laguna de Bay and Pasig River in the early 1980s was intended to prevent this back flow, and at the same time increase the storage capacity of the lake to meet further demands for domestic and irrigation water. A related project is the 80% completed Manggahan Floodway on the norhtwest, which will divert flood waters from Marikina River, a tributary of Pasig River. This would further increase lake storage and simultaneously minimize flooding of urban Metro-Manila.

The storage capacity of Laguna de Bay, at full operation of the Manggahan Floodway and Napindan Hydraulic Control Structure, will amount to a maximum of 950 million cubic meters. The current demand for the lake's waters is 8.91 cubic meters per second (CMS) for industrial use, and 46.3 CMS for the power plants. The estimated domestic water demand is 25-30 CMS, while the projected irrigation service area of 30,000 hectares will require approximately 70 CMS at full operation.

Since the massive infrastructure projects were designed to increase the lake's storage capacity the consequence would be periodic submergence of the flood prone areas of the lakeshore. In fact floodwaters rose to inundate lakeshore communities after a prolonged and unusually high precipitation in October-November 1986. The lake level receded to normal levels only after 2 months leading to countless suffering including high mortality and morbidity due to gastroenteritis and other water-borne diseases.

The climate is characterized as tropical monsoonal with pronounced dry and wet months. The average rainfall is approximately 2070 mm with a mean temperature of 27°C. Bright sunshine amounts to some 2,100 hours per year.

Limnology of Laguna de Bay

The water quality of Laguna de Bay has been monitored by the Laguna Lake Development Authority and also by UPLB and SEAFDEC since 1976. This tropical shallow lake (mean depth of 2.8 meters) is relatively well mixed. Thus, thermocline formation is not expected to occur, except during hot days when surface waters may reach 35°C at mid-day, while the bottom waters measure around 30°C. On the average, water temperatures are minimum at 24 to 26°C from December to February, and maximum 28 to 32°C from May to August. This gives a seasonal fluctuation of around 8°C.

The water is normally neutral to slightly alkaline (pH range of 7.4 to 9.2 in 1985). Secchi disc reading, however, seldom exceeds 0.5 m. The sources of water turbidity are both organic (mainly algal biomass) and mineral (siltation from catchment basin) and lake bed sediments during turbulence. Sediment yield of catchment is estimated at one million cubic metres per annum. Phytoplankton biomass amounts to 5-15 g m^{-3}, with maximum values reaching 70-95 during algal bloom years, e.g. in 1973-74. The turbidity ranged from 30-48 milligrams per litre as SiO_2 in 1985 (LLDA, 1985).

Current net primary production averages around 0.6 - 0.9 g carbon per square meter per day. This can be translated to 1.75 to 2.6 tons of fish (phytoplankton feeder) per hectare per year or an annual potential fish yield of 158,000 to 234,000 tons for the whole lake.

The net primary production also indicates that Laguna de Bay is eutrophic. Algal blooms have occured especially intense in the early 70's when massive fish kills were observed. The most frequent taxa during the bloom are the blue-green algae, notably *Microcystis, Oscillatoria* and *Ana- baena.* The limiting nutrient is assumed to be nitrogen and not phosphorus, since the latter occurs at high ambient concentrations due to the volcanic nature of the catchment basin. During 1985, the annual mean concentration of inorganic nitrogen in the lake waters amounted to 167 µg/l while inorganic phosphorus concentration was 64 µg/l (LLDA, 1985).

The nitrogen and phosphorus loadings from river inflows estimated last in 1976 were around 3,900 and 900 metric tons, respectively. About 60% of these loadings are attributed equally to domestic and livestock wastes. There exists practically no treatment facilities for waste-waters and solid waste management is likewise lacking. Coliform counts often exceeded safety levels and in fact pathogens have been found to occur. Loadings of biochemical oxygen demand (i.e. the organic pollution) were estimated in 1976 at around 50,000 metric tons per annum. Half of this is ascribed to industrial sources, while the other half stems from domestic wastes. The highest BOD contributor is the agro-industrial sector (12,000 metric tons in 1984).

Toxicants in the form of oil, heavy metals, pesticides and industrial compounds are of concern to lake managers, but very little monitoring has been done. Oil barging (more than 15,000 barrels daily) and about 5,000 motorized fishing/transport boats ply the lake waters and provide the main sources of oil pollution. Pesticides and fertilizers are contributed by irrigation return flows and runoffs from about 50,000 hectares of agricultural lands, including 30,000 hectares of rice paddies. The banned pesticide DDT has, for example, been detected in human milk from lakeshore residents. Nitrates concentration in groundwater wells is high and has been correlated with known cases of methemogloninemia among infants around the lake.

Since 1984, some 876 industrial estates have been established within the Laguna de Bay region. Half of these industries use water for unit processes and operations, while only one out of five has wastewater treatment facilities.

Two thermal power plants (in Sucat and Pililla) with a combined generating capacity of 1500 MW use lake water for cooling. However, lake limnology, including fisheries, is not considered to be adversely affected by this highly concentrated thermal pollution. Hydroelectric (in Caliraya) and geothermal power (330 MW near Los Banos) is also produced within the lake region, but their impact on the lake is also considered minimal and site-specific.

Conflicting demands on Laguna de Bay

The present and intended beneficial uses of Laguna de Bay are:

* water supply source for Metro-Manila and basin communities in 1990's,
* fisheries (aquaculture and catch fisheries) and major fish supply for Metro-Manila and basin communities (at 220,000 metric tons in 1982)
* irrigation water source for some 30,000 hectares of paddy rice lands,
* navigation for commercial and industrial goods (such as bunker oil, fingerlings, consumer products and passenger services),
* industrial uses (process and cooling water for power plants and factories),
* hydroelectric power generation,

* recreation (boating and limited bathing),
* waste disposal (as sewage for domestic, industrial and agricultural effluents),
* flood control for downstream Metro-Manila areas (but to the detriment of lakeshore communities).

This variety of utilization demands particular (often conflicting) levels of water quality and quantity. As with other lakes in the world experiencing population pressure, urbanization and industrialization, Laguna de Bay represents a great challenge to environmental and resource managers.

9.3 WASTEWATER CONTROL IN LAGUNA DE BAY REGION

In the remaining part of this paper is presented the salient features of wastewater control in the Laguna de Bay region.

Wastewater control in the private sector

Industrial and agro-industrial waste control

In the Laguna de Bay watershed, the domestic waste contribution to total BOD load is nearly equal to the industrial waste contribution. The highest BOD contributor, however, is the agro-industrial group. Livestock industry takes up more than 10% of the total industrial and agro-industrial establishments within the watershed. Organic waste load from commercial livestock farms was approximately 12,000 metric tons in 1984 as compared with 11,400 metric tons in 1976. On the other hand, COD and TSS loadings from the textile/garments industry, food processing industry increased during 1980 to 1984.

Since 1984, there have been 876 industrial establishments within the Laguna de Bay watershed, 49% of which belong to the "wet" (water is used for unit processes and operations) industry category. Among the "wet" industry group, 183 had installed waste water treatment facilities.

The common waste water treatment processes employed are given in Table 9.2 along with the expected and actual efficiencies.

Community waste control

There are no centralized systems located within the basin areas except in some recent housing developments. Even among these developments only one has put up its sewage treatment works.

Table 9.2
Waste water treatment process efficiency

Wastewater treatment processes	Percent removal	
	Expected based on BOD_5	Actual, based on COD
Primary and activated sludge	90	77
Private and aerated lagoon	90	95
Primary and Rotating biological contactors	90	78
Oxidation ponds	90	90
Primary and chemical treatment	60	5

Sanitary facilities include units with central collection, septic tanks and sealed tanks. These can be the automatic flush type or the pour-flush type.

Water-carried (septic tank) and semi-water (pour-flush) disposal systems constitute approximately 60% of the sanitary facilities in Rizal Province and 40% in Laguna Province. Pit latrines are still being used by a large number of dwellings.

Croplands

There are approximately 50,000 hectares of irrigated agricultural land including about 30,000 hectares of rice paddies in the basin. Under the old practice in which irrigation water is applied continuously following fertilization, a significant quantity of nitrogen may be lost in the drainage. Nitrogen inflow into the lake is of particular concern because eutrophication represents the most significant factor in lake water quality management of Laguna de Bay since the lake is nitrogen-limited. There is evidence that a majority of the farmers in the basin now practice good fertilizer and irrigation management. Studies on fertilizer uptake and infiltration show that the nitrogen losses to the lake could be halved.

Oil barging

The lake is now used for barging about 16,000 barrels of oil and petroleum products daily. It is well known that oil is one of the most widespread and serious contaminants of surface waters. While the barging of oil in the lake and its associated industries (power production and oil refining) will always present water quality problems, experience elsewhere has shown that with a careful surveillance, this problem may be controlled to a reasonable extent most of the time. At present, almost all barges plying the lake are double hull barges to reduce the risk of oil spillage. All are provided with oil spill containment booms to prevent the spread of oil in case of accidental spill. In addition, strict adherence to barging permit requirements is observed.

Wastewater control in the government sector

Thermal power

The Malaya Thermal Plant in Philla has an average generating capacity of 650 MW. In the process, it produces sanitary waste, which is treated by oxidation and hypochlorination and process wastewater from dust handling and preheater handling, which goes into a neutralization and settling basin before discharge into the lake.

The average production of the Gardner-Snyder Thermal Plant in Sucat is 850 MW. Sanitary waste is directed to a septic tank, which overflows into the discharge channel of the cooling water. On the other hand, spent resin from the demineralizer and wash-down from the dust collection are dumped into the ash settling basin, which has no overflow. Cooling water is discharged into a channel which is separated from the main body of the lake by a 530 m long embankment on the east and a 50 m wide floating oil spill containment boom at the outlet at the northern portion of the channel.

The problem of thermal pollution in the Laguna de Bay has been the subject of preliminary assessments including the National Pollution Control Commission (NPCC) study of effects of the Sucat and Pililla power plants on fish and plankton. These plants do exert some effects on the lake ecology such as the effects of the thermal loads in the discharged cooling water and the effect of the plant operations on aquatic biota circulated through the plant (thermal and mechanical effects). However, based on experience elsewhere, including detailed evaluations made in Thailand for a proposed nuclear power plant on the Inner Gulf of Thailand and the available information on Laguna Lake limnology, including fisheries, it is believed that the thermal effects of the existing power plants will not significantly alter the basic lake limnology.

Geothermal power

The Macban Geothermal Plant is situated norteast of Los Banos in a mountainous area. The plant includes six 55 MW units, the last two having been made operational in late 1984.

The steam comes from wells drilled for the power plant. The condensed water is re-injected in the geothermal field to maintain the water balance;

no water is discharged to the lake or its effluent.

Hydroelectric power

The Caliraya hydroelectric power scheme does not change the water resources except for the additional evaporation lost from the two lakes estimated at 19 million cubic meters per year. Operation does not affect the water quality of the lake as the Caliraya River flow will have ended in the Lake anyhow.

The Kalayaan pumped storage development does not change the water resources regime of the lake except for daily and weekly modulations of the volumes exchanged between the East Bay and the Caliraya Lake. However, the maximum drawdown during the weekend will lower the lake level, on an average, by 7 to 8 millimeters, which is negligible. Mixing of the water between the East and the South Bays will be increased. Operation of Kalayaan development does not cause any pollution to the lake.

Summary of assessment

Based on the characteristics of industrial/agro-industrial effluents during the 1980-1984, compliance to the 1982 effluents standards was analyzed, and the result is given below in Table 9.3.

Table 9.3
Degree of compliance to effluents standards

Parameters	Standards for class "C" effluent	Percent of time stated standards not exceeded	
		without treatment	with treatment
BOD_5, mg/l	80	60	80
TSS, mg/l	75	75	84
Oil & grease, mg/l	10	83	93
Phenols, mg/l	0.1	66	82
pH, units	6.5-7.5	62	72
Colour, Pt-Co units	100	52	61

It would be premature to voice out optimism at this time as if water pollution has finally been solved. What the figures merely indicate, at this time, is the "attainability" of the standards. Moreover, since the sample size used in arriving at the above figure was only a fraction of the total number of plants, in real terms the pollution remains severe. This latter situation was shown by the water quality indices of the major rivers in the watershed during the period 1982 to 1985.

9.4 INSTITUTIONAL FRAMEWORK FOR EPM IN LAGUNA DE BAY REGION

In the early 60's, threats from the rapidly changing character of the lake region were perceived by political leaders in the area, notably the governors of the provinces of Rizal and Laguna, who sought the enactment of a piece of legislation to control and manage the resources of the lake. The problems as then perceived were subsumed under the rubric of social and economic development,

* poor living standards and a rapidly increasing population growth;
* decreasing fish yield from the lake;
* deteriorating water quality as a result of pollution and algae bloom;
* proliferation of industries along the lakeshore.

A bill was thus introduced in Congress, and on July 18, 1966 Republic Act 4856 was enacted creating the Laguna Lake Development Authority (LLDA). With the creation of LLDA an institutional framework for an EPM scheme to achieve rational utilization of the lake resources under a watershed management approach was eventually realized.

LLDA was given the broad mandate to

... promote and accelerate the development and balanced growth of the Laguna Lake Area and the surrounding provinces, cities, and towns ... within the context of the national and regional plans and policies for social and economic development ...

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CHAPTER 10

MANAGEMENT OF RESERVOIRS IN BRAZIL

10.1 INTRODUCTION

Reservoirs as an intermediate system between rivers and lakes have many specific mechanisms of functioning (Margalef, 1983; Dussart, 1984).

The process of following up the ecological changes produced by reservoir construction, and its evolution after filling up is a theoretical and practical study of regional significance. Reservoirs are a point of reference in the river system, since its evolution, changes in water quality and possible eutrophication, alterations in aquatic flora and fauna reflect the watershed management and the uses of the terrestrial system. When placed together with the intrinsic mechanism of functioning of the reservoir itself (turbulence, residence time, circulation, pattern of stratification) an environmental pattern emerges with an output representing ecological, economic and social inputs.

The utilization of a reservoir as an information system, includes a reference in time extremely useful in following the evolution of the terrestrial system, its possible deterioration and uses (Margalef, 1976).

The reservoirs in South America and particularly in Brazil are an important ecosystem in the hydrographical network. One of the basic points is the reservoir as a central focus in river basin management; this includes provision of environmental data supplied throughout monitoring and research before and after construction. Several ecological problems related to the reservoir as an ecosystem were discussed by Margalef, 1976; Armengol, 1977; Toja, 1984; Baxter, 1977; among these, the colonization of reservoirs, the characteristics of the fauna and flora and twin evolution, and changes in the food chain dynamics were given emphasis. Panday (1987) published a summary on man-made lakes and human health mainly in connection with tropical reservoirs; Ploskey, 1985, published a review on impacts of terrestrial vegetation and the impoundment on reservoir ecology and fisheries in the United States and Canada.

Reservoirs are complex systems to manage. Since they are intermediates between lakes and rivers, several characteristic features should be taken into account for the practical purpose of management, mainly: spatial heterogenity, compartimentalization, advective currents, water level fluctuation and residence time. If the reservoirs are placed in a sequence in a river, then the functioning of the whole series should be considered for management.

Adequate management of a reservoir or a system of reservoirs, relates to the following sequences:

1. **The environmental impact assessment** before implementation in the planning stage.
2. **The cost/benefit analysis** of the impoundment before construction.
3. **The monitoring previously to the construction.**
4. **The monitoring during the construction.**
5. **The follow-up measures** after the construction of the reservoir (including perspectives for multiple use).

The accumulation of basic data in this sequence is fundamental to the understanding of future processes in the reservoir mechanisms and as a basis for prognosis of the evolution of the ecosystem subjected to human activities.

Although many reservoirs are built up for the purpose of hydroelectric production, the management should involve perspectives for multiple uses. Another aspect that should be dealt with in the management of reservoirs is the fact that in many developing countries, these large artificial systems are used as a basis for regional development, and are therefore being catalytic agents for several multipurpose actions that undoubtedly will affect the future reservoir. The comparative monitoring and research for reservoirs is basic to the understanding of the mechanisms of functioning and is also the key to provide tools for management. However, each reservoir or each reservoir system (if they are placed in a cascade) are to be considered as a unity on which management problems should be concentrated. In this context an overview of some management plans, techniques and actions is shown for the Brazilian reservoirs. A brief analysis of the main problems is given.

10.2 RESERVOIRS IN BRAZIL

Reservoirs, in Brazil, play an important ecological, economic and social role. The tradition of building up small public reservoirs for water supply in the Northeast is almost 100 years old. In the Southeastern and Southern region, several small reservoirs (up to $5*10^7$ m^3) were constructed approximately 50-60 years ago with the purpose of hydroelectric production.

The large reservoir system in the Southeastern and Southern regions, were built up succesively in the last 30 years as a consequence of the increasing need for energy. The pattern of impoundment of river, followed a cascade system with a generally large accumulation reservoir in the upper catchment area and flow though smaller reservoirs downstream. Since the hydroelectric potential of the Southeastern and Southern regions is almost exhausted the new dams are planned for the Amazon and Northeastern (Amazon tributaries and S. Francisco River). The program of expansion of hydroelectricity until the year 2010 includes the construction of 86 new reservoirs in the various regions of Brazil including a few more in the Southern and Southeast (Eletrobras, S.A., 1987). Thus this entire development of artificial ecosystems posed several problems of management and it is a case study of importance in South America.

The general ecological consequences of river impoundments are related to several factors, among which the most important ones are the size, volume of reservoir, residence time of the water and geographic location. Many papers have reviewed and discussed these effects: inundation of valuable agricultural land; impairing of fish migration; loss of terrestrial vegetation and fauna; changes in the river fauna and vegetation; hydrological changes in the river downstream; interference on the sediment transport regimes; the spreading of waterborne diseases by producing a favorable environment for vectors; the loss of cultural/historical heritage; the social effects on the local populations including relocation; changes in economic activities and traditional land uses and practices. Geophysical problems due to water accumulation were also pointed out; several changes downstream were reported (Ackerman et al., 1973: Scope, 1972; Balon and Coche, 1974; J. Van der Heide, 1982; Baxter, 1977; Barrow, 1983; Tundisi, 1986a). All these consequences are due to **direct or indirect** impacts.

Most of the large reservoirs were planned *only* for hydroelectric power, thus the follow-up of the reservoir after filling includes a framework for monitoring and research to be available for management, multiple uses, and regional planning. After the initial impact several changes occur at a later stage; Bonetto et al. (1987), for example, lists for reservoirs in Argentina a series of environmental problems due to increasing eutrophication, siltation due to deforestation, climate and hydrological alterations, retention of suspended solids and influence on fluvial valleys and river deltas; effect from industrial effluents, nutrient accumulation and salt accumulation.

10.3 RESERVOIRS IN S. PAULO STATE AND IN THE MIDDLE TIETE RIVER: a comparative case study, and management problems

S. Paulo State has experienced a fast economic growth in the last 30 years as a result of industrialization, large agro-industrial projects and growth of urban population. This pattern resulted in the following environmental problems:

- i **Excessive deforestation** (only 2% of the original vegetation cover from the beginning of the century remain).
- ii **Large network of roads.**
- iii **Increase of soil and water pollution.**
- iv **Large scale reservoir construction.**
- v **Eutrophication of inland waters** (rivers, wetlands, reservoirs), estuaries and coastal ecosystems.
- vi **Deterioration of water quality** for multiple uses (including groundwater).

Therefore the situation today is a conflict between economic activity and environmental planning and management, as it occurs in many other regions or countries (Numata, 1985).

The large reservoir projects and the network produced successively in the hydrographic basin, were the last step in the process of land occupation in the State of S. Paulo. Today the inundated area is around 15,000 km^2, approximately 5% of the total area of the state. This pattern of reservoir construction followed the extensive deforestation, development of agriculture, and stimulated the large scale technological investments in agriculture, and industry. When this reservoir system is considered in relation to the economic development, population growth and geographic situation, it becomes evident why these large artificial ecosystems are a key indicator of watershed uses (Fig. 10.1).

S. Paulo State is thus a case study of considerable size, complexity and importance in Brazil with the environmental planning as a central theme. The time sequence of construction of reservoirs and the geographic distribution can be used in this context. Comparison of the evolutive process in the reservoirs can thus produce valuable information for local and regional management and for application in the other hydrographic basins.

Such a framework was developed in a comparative project launched in 1979 (FAPESP - Typology of reservoirs in S. Paulo State - Tundisi, 1981).

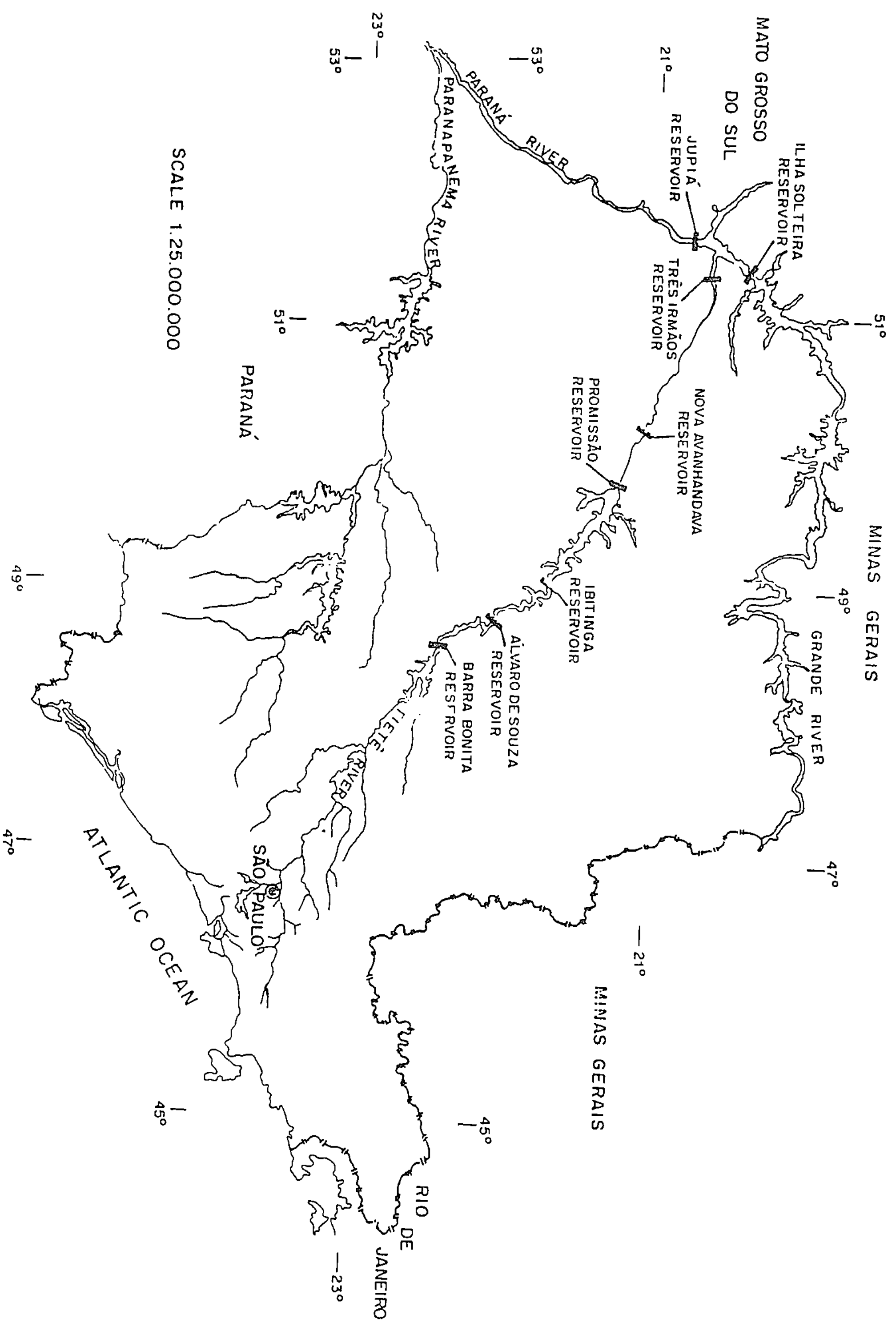

Figure 10.1 Watershed. Main reservoirs in S. Paulo State. From Tundisi (1988).

This work was the first step in the establishment of a comparative data bank; cluster analysis is in progress today. The project also showed that the reservoirs in the Middle Tietê river are good indicators of watershed changes; the determination of the Trophic State Index (TSI) by the use of Carlson (1977)- method gave a further insight into the classification of reservoirs and land use in S. Paulo State. The downstream effects of these large dams of the upper Parana System may be several, including siltation, gradual eutrophication, frequency of water bloom and increase in toxic substances. Although each reservoir eliminates part of the nutrient cycle, the gradual increase in the loading of phosphorus and nitrogen is still evident from recent data (Tundisi et al., in press).

Thus, these large reservoirs in a cascade in the rivers of the upper Parama Basin in southern states (volume larger than $4*10^7$ m^3) present the following problems:

Main uses: hydroelectricity, transportation, recreation, limited irrigation, sport-fisheries, commercial fisheries, water supply.

Problems: heavy eutrophication due to domestic agricultural and industrial waste, siltation, pollution with herbicides and pesticides, contamination, water blooms of *Microcystis sp.* and *Anabena sp.* complex social problems due to relocation.

Management activities and actions

A. **Control of eutrophication by treatment of waste disposal**, and regulation of flushing rate.

B. **Watershed protection** by the actions of prefectures (cooperative system for monitoring and for proposing remedial measures).

C. **Preservation and reconstruction of gallery forest** with native species.

D. **Fishery stations** for providing fish stocks to the reservoirs.

E. **Re-forestration** of the shore line to avoid siltation and eutrophication.

F. **Monitoring activities** to control eutrophication and toxity from heavy metals.

G. **Relocation measures** to provide compensation for loss of agricultural lands and crops.

However, several integrated measures for the management of these reservoirs have to be implemented in a more co-ordinated manner: for example, several activities were developed for one reservoir only and not for the whole system in the cascade, or the entire watershed. Many management activities were proposed as a consequence of problems such as eutrophication (sectorial management).

In many cases, few preventive measures were taken due to a poor prognostic and lack of a more general and integrated conceptual overview. One unforseen problem in some reservoirs was the social conflict caused by relocation. In the well established small farms in the southern region the relocation is a key issue due to loss of productive land and several years of production.

Monitoring of physical, chemical, biological, and geological variables is relatively well developed. Some monitoring and data bank for social aspects has been attempted in a few reservoirs.

10.4 RESERVOIRS IN THE SEMI-ARID REGION

Small reservoirs

The small impoundments in a semi-arid region in Brazil (located between approximately 5° South to 25° South and 35°-45° West) with a size greater than one million cubic meters less than 10 million cubic meters were built up with the purpose of river regulation, irrigation, water storage for general purposes and fish production. The small systems produce little impact in the river system. However, they present following problems: Salinization, spreading of water-borne disease (*Schistosomiasis*), general sanitary problems in general. Management is devoted to regulation of water supply down-stream, fish production, water allocation for multiple uses, control of aquatic weeds, salinization and measure to improve sanitary conditions. Prevention of spreading of *schistosomiasis,* and problems of water quality in general (including effects of salinization) are some of the unsolved problems resulting from lake management measures or lack of coordinated efforts. Monitoring is at in early stage.

Large reservoirs

Large reservoirs in semi-arid region, mainly in the S. Francisco River Basin were constructed with the purpose of hydroelectric production and other uses, mainly irrigation and fish production. These reservoris, in a cascade, produced the following problems: extensive changes in river fauna, increasing siltation, eutrophication (due to simultaneous fertilization and irrigation) increasing contents of pesticides and herbicides, frequent water blooms due to eutrophication. **Management** is concentrated on allocation of water resources for multiple uses, such as hydroelectricity production, irrigation, fisheries, construction and maintenance of small agriculture units (integrated agriculture with fish farming, duck farming and pig farming) increase in the agricultural production, relocation of population (construction of new towns, and villages, provision of facilities for new residents relocated from inundated areas).

Relocation in these regions is related to the change in activities (from farmers to fishermen) creating complex social problems. **Monitoring** is at an early stage. Recently, however, extensive research work by social scientists was carried out for some of these reservoirs prior to the relocation, during the reservoir construction. Social scientists assisted in the subsequent conflicts generated by relocation; compensation for loss of agricultural land and crops was the central problem in the social conflicts.

10.5 LARGE RESERVOIRS IN THE AMAZON TRIBUTARIES

The large dams in operation in the forested areas of the tropics in the Amazon, present another series of problems of an entirely different nature. Besides the waste of valuable timber (Monosowiski, 1984) the loss of a diversified and rich fauna and flora, with a high genetic variety (including probably species of medical interest) the decay of the drowned vegetation produced eutrophic and contaminated water with high concentration of hydrogen sulphide. The general effects on the reservoirs in the Amazon Region may be listed as follows: (from Goodland, 1977)

Chemical effects	Biological and human effects
Aerobic decomposition	Loss of environmental "services"
Anaerobic decomposition	Loss of timber resource
Oxygen reduction	Loss of wildlife habitat
Production of methane	Proliferation of waterweeds
Production of hydrogen sulphide	Curtailed multiple use
Chemical precipitation	Increased disease vectors
Eutrophication	Impained water quality
Increased acidity	Impediment to access
Increased corrosion	
Production of hydrogen	

Physical effects

Reduction of reservoir volume
Reduction of vertical circulation
Mechanical interference with multiple use
Mechanical interference with dam
Biological and human effects

An attempt to compare Amazonian reservoirs with African ones, would not work: the African reservoirs are mostly built up in savanna regions, the hydrogeo-chemistry and ionic composition of the water of the Amazon tributaries is diverse of the African rivers, and the pH of the Amazon waters is low and acidic (Junk and Mello, 1987).

The first large reservoir constructed in the Amazon region, Tucurui Reservoir, has an extensive action plan for management, a pilot experience that may be useful for other systems already under construction. The aim of this plan is to establish an integrated management policy involving environmental and social aspects in order to insert the reservoir construction in the regional development plan. The main objective of the action plan is to implement a management system that encompasses the reservoir itself and its area of influence considered for this purpose as the area in which the natural environment influences the reservoir (Eletronorte, 1987).

All the management activities are included in the following five basic problems:

1. Environmental data base expansion program
2. Environmental control program
3. Regional integration program
4. Multi-purpose program
5. Global study development program

The environmental control program includes the following activities:
- Limnology and water quality
- Mathematical modelling of water quality.

Eletronorte has applied the following models in its prognosis:
1. **Vollenweider's Model** (total phosphorus): used to analyse comparative aspects between reservoirs.
2. **Oxy-Stratif Model**: used to analyse the average behavior of the reservoir from the viability to the stage of operation.
3. **Wqrrs Model**: used, though in a preliminary way, in the stage of operation. It is not adapted to tropical conditions.

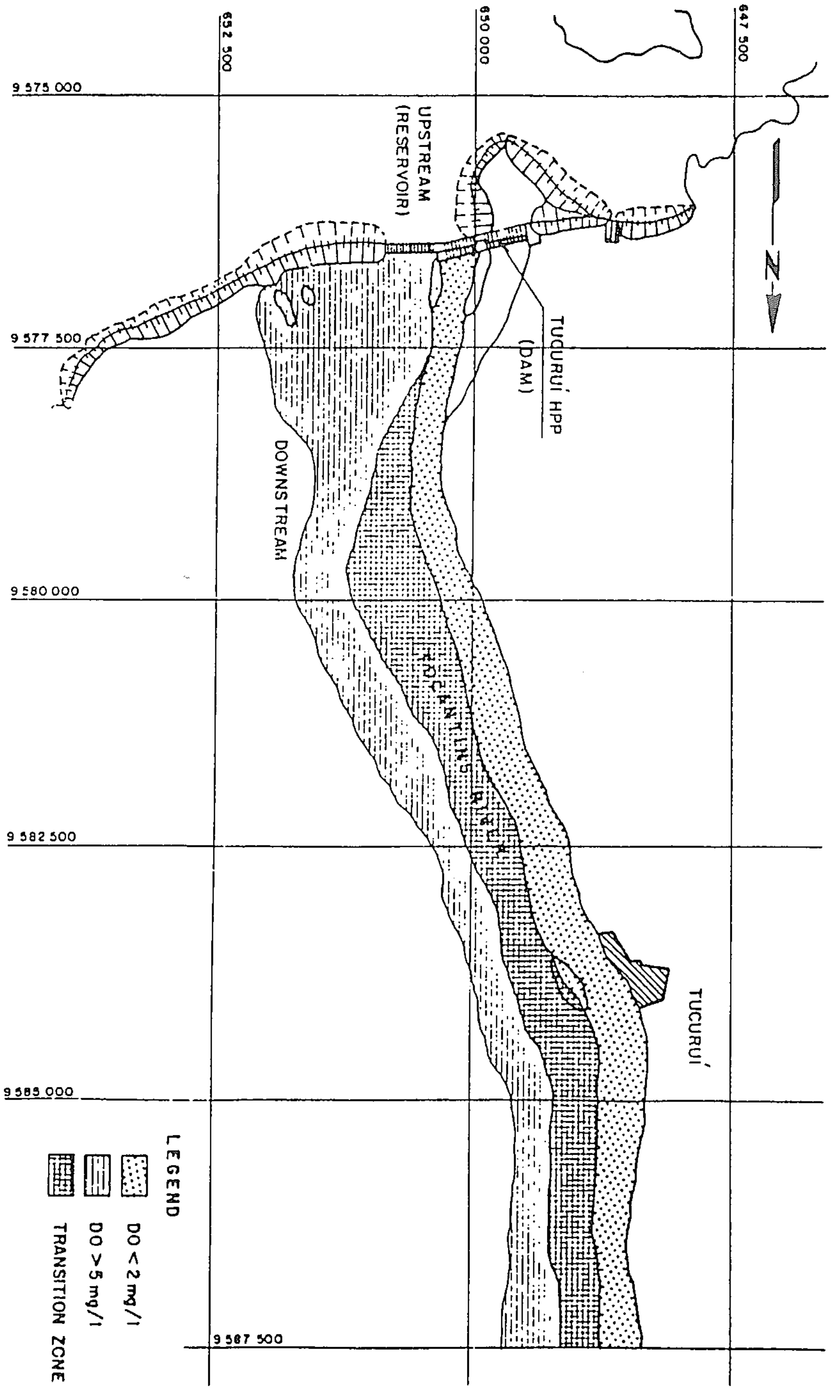

Figure 10.2: Schematic representation of downstream water-quality in Tucurui reservoir.

The results obtained from those models provide data for the following analyses:

1. Prognosis of impact on the water quality.
2. Alteration in the present and future use of the water upstream and downstream of the dam.
3. Impact on the ichthyofauna.
4. Evaluation of the need for deforestation, of the area and quantity to be deforestated.
5. Prognosis of macrophyte population (qualitatively).
6. Indication of alterations in the dam structures (levels, water intakes, water level for operation, and so on) that would improve the water quality.

The regional integration program includes: **socio-economic cultural environmental and program of environmental education.**

This synthesis (Hino, 1988) shows that such new complex ecosystems had also an enormous impact on the management plan and on the implementation of actions to insert the reservoir in the regional development plan. For this a comprehensive and detailed plan of integration was derived and is taking full action.

Underlying this attitude is a policy for the regional insertion of the projects, which consists of the adoption of guidelines that might favour the greatest possible integration of the projects into the regional economy, supporting and stregthening the urban and regional structure, thus providing a maximum absorption of investments by the population and the regional economy, reducing the economic and social unstructuring processes that the project may bring to the region.

The area coverd by the socio-economic and cultural study are:

1. **Socio-economic and cultural studies** of the projects' areas of influence.

2. **Public health studies.**

3. **Urban and regional infrastructure studies.**
4. **Anthropological studies of indigenous populations.**

5. **Archeological salvage studies** of the projects' direct areas of influence.

6. **Specific studies for the relocation of urban and rural**

populations directly affected by the projects.

7. **Specific studies of waterside populations** located downstream of the projects.

Table 10.1
A comparative management program for Lobo Reservoir, Tucurui and Itaparica Reservoir.

	Lobo (Broa) Reservoir (S. Paulo State)	Tucurui Reservoir (Tocantins River)
Water quality	Maintenance of present water quality for recreation, domestic use. Modelling of water quality in progress.	Improvement of water quality for turbine protection, fisheries and general use. Modelling of water quality in progress.
Population	Maintenance of present level of activity (small scale agriculture, recreation). Env. education system in progress.	Increase in the number of jobs, agricultural development. Relocation. Improvement of sanitary conditions.
Protection and conservation measures	Maintenance of spatial heterogeneity (Gallery forests, Macrophytes). Prevention of eutrophication. Protection of rivers. Monitoring of rivers.	Program of regional integration and insertion of the project. Protection of islands. Marginal areas. Protection of downstream areas.
Multiple uses of the reservoir	Recreation, small scale fisheries, limited irrigation, scientific activities, fish production. Hydroelectricity. Training in environmental sciences, limnology.	Fisheries, hydroelectricity, transportation. Scientific studies, training.
Other general measures for correction and protection. Preventive and corrective actions	Area of environmental protection. Management program in implementation. Legal actions.	Establishment of protected area around the reservoir. Control of water quality downstream and support of populations downstream.

Table 10.1 (continued)

	Itaparica Reservoir (S. Francisco River)
Water quality	Maintenance of water quality for irrigation, fisheries, domestic use. No modelling.
Population	Increase in the number of jobs. Fish farming, small scale agriculture. Relocation. Prevention of disease.
Protection and conservation measures	Regional integration. Protection of fish fauna. Reforestation. Protection of downstream areas.
Multiple uses of the reservoir	Hydroelectricity, fisheries. Fish farming, irrigation.
Other general measures for correction and protection. Preventive and coorective actions	Construction of farm villages. Improvement of sanitary conditions downstream.

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CHAPTER 11

ENVIRONMENTAL MANAGEMENT OF THE SAGULING DAM

11.1 INTRODUCTION

Indonesia is a large archipelagic country consisting of more than 13,000 islands. The total population in 1984 was approximately 167 million people. Most of the population (62%) are concentrated on Java Island which is only approximately 7% of the total area. About 70% of these are living in rural areas and subsist from agricultural activities as farmers or agricultural labourers. They are also characterized by a high rate in annual population growth (the country average is 2.34%). As a consequence, there has been an increasing demand of land to fulfil the requirement of food. Since the availability of arable flat land is limited, the people is forced to extend their land to a more steep area. Forests are cut for developing agricultural land, while many marginal lands are also utilized. In most cases those practices were carried out without considering land and water conservation which subsequently cause deterioration of land and hydrological function accompanied by increase of erosion, flood and drought. This has been the prevailing condition in Java Island.

Environmental problems in Indonesia are primarily due to the prevailing poverty. Under the existing conditions the population density has reached or exceeded the carrying capacity of the environment. Under such conditions, environmental amelioration occurs with development. The benefit of a project could be enhanced by mitigating the negative impacts and enhancing the positive impacts of the project. Without development, environmental conditions will degrade even more rapidly.

The development of Saguling dam displaced a large number of population and inundated extensive agricultural land. It has been estimated that the displacement of the population may increase the population density in the surrounding area, and this may aggravate the situation, while the dam will be threatened by high sedimentation rate which may shorten the life time of the dam.

The decision of constructing the dam seems, however, the best alternative, although it will cause major impacts on the environment. If a decision of "not developing the area" was taken, sooner or later the forest clearing would become more prevalent, and the watershed become more deteriorated.

This case study is mainly based on study reports on Saguling dam made by the Institute of Ecology (Institute of Ecology, 1979 & 1981). Most of the data and concepts are cited from these reports.

11.2 LOCATION

The Saguling dam is situated in Citarum river in West Java province. It is the largest river in the province, about 325 km long. The watershed covers about 6,000 sq. km., which areas are under the administration of eight regencies (*kabupaten*). Most of the upper part of the watershed, where the Saguling dam is located, belongs to Bandung regency (Fig. 11.1).

11.3 MAJOR WATER RESOURCE DEVELOPMENT PROJECTS IN THE RIVER

There are presently two large dams and one small dam in the river, i.e. Saguling, Jatiluhur, and Curug dams. Another large dam will be in operation in 1988, i.e. Cirata dam which is located at the upper part of Jatiluhur and one small dam will be established inbetween Cirata and Saguling dams, i.e. Rajamandala dam. Thus, there will be a series of five dams in the Citarum river. Data on these dams are presented in Table 11.1. Discussion in this paper will be focused on the Saguling dam.

The dam is a rockfilled dam, 97.5 meter in height and 301.4 meter in length. The high water line of the reservoir is 645 meter. For the establishment of the dam, extensive land was needed and a large number of population was affected. It inundated settlement (132.7 ha), ricefield (2,257.8 ha), dryfield (1,925.5 ha), plantation/estates (344.2 ha), river/road, etc. (745.4 ha), or in total 5,606.6 hectares of land were used for the project development.

Saguling plays an important role in the electricity system on the Java Island with the capacity of 700 MW, which can be enlarged to 1,400 MW.

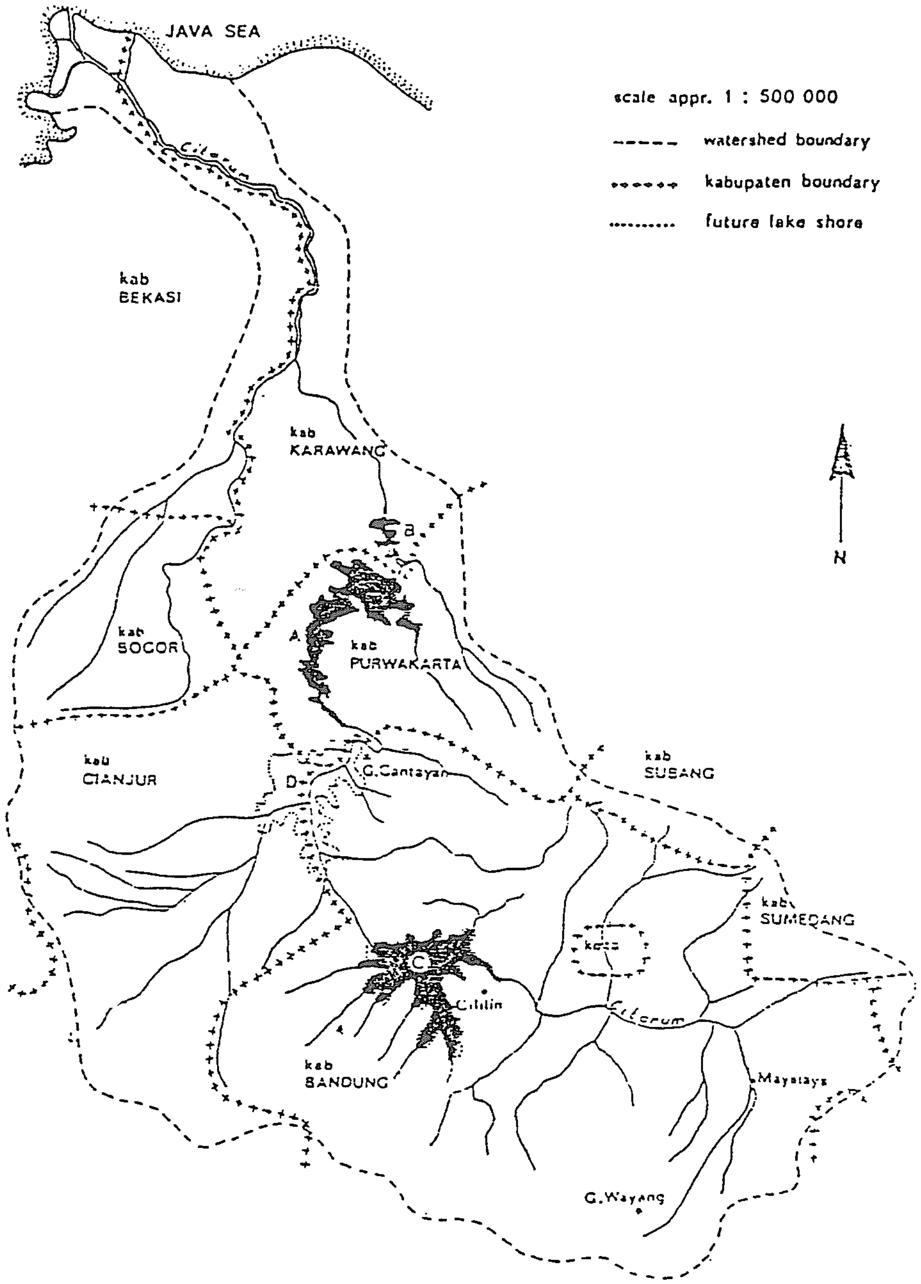

Figure 11.1 The Citarum watershed. Within the area all surficial water flows into the main river Citarum. It has a natural boundary which is formed by mountain ridges between the mountain peaks. A = Jatiluhur lake; B = Curug lake; C = Saguling lake (planned); D = Cirata lake (planned).

Table 11.1
Dam development in Citarum River, West Java, Indonesia.

No. dam	Year of establish-ment	Extent (ha)	Major function	Installed capacity (MW)	Extent of land irri-gated (ha)	HWL
1. Saguling	1985	5,606	Electric generation	700	-	645
2. Cirata	1988	6,200	Electric generation	500	-	221
3. Rajamandala	planned	-	Electric generation	57	-	252
4. Jatiluhur	1975	8,300	Irrigation	150	260,000	107
5. Curug	1975	700	Irrigation	6.2		26.4

11.4 ENVIRONMENTAL CONDITIONS OF THE AREA

Climate

The annual average temperature in the project area is about 23.2 °C, while the mean annual rainfall is about 2313 mm. The rainfall of the area is influenced by the monsoon climate. The rainfall is classes B and C in accordance to Schmidt and Ferguson.

Hydrology

The hydrological condition of the Citarum basin is evaluated through several phenomena, i.e.:

a. Discharge fluctuation

The analysis of discharge fluctuations in Citarum is based on the discharge data computed by DPMA (1978). It shows that the discharge during the rainy season in the period of 1970 to 1973 is higher than the preceeding period, while the discharge during the dry season in that period was lower. For example, the monthly discharge in March in 1950-1959 was 120 m^3/second and that in 1970-1973 was 161 m^3/second, while the monthly discharge in September in 1950-1959 was 25 m^3/second, and in the same month in 1970-1973 only 13 m^3/second.

b. Ratio between maximum and minimum discharge

The mean value of the ratio between the total discharge in the rainy and dry seasons during the period 1923-1940 was 3.04 and in the perioc 1963-1977 it was 4.13. The ratio between maximum and minimum discharges during the period 1923-1940 was 62.8, while it was 98.6 in the period 1963-1977. This means that from 1923 through 1977 the discharge in the rainy season has increased by a factor approximately 1.5 relative to that of the dry season.

c. Erosion rate of the upper Citarum basin

The erosion rate in each year was calculated on the basis of the catchment area of Citarum above Nanjung, which is about 1718 km^2. (Nanjung located at the point where Citarum river enters the reservoir). It shows that the erosion rate ranges from 1.82 to 5.20 mm/annum and the mean erosion rate is 3.35 mm/annum.

Considering the above conditions, it may be concluded that the hydrological conditions of the upper Citarum basin are changing, particularly during the last decade. Unfortunately this change is leading to an increased erosion rate.

Eutrophication

The total amounts of inorganic nitrogen and total phosphorus are already sufficient to cause a significant bloom of algae or aquatic weed (Leuschow et al., 1970). The high level of nutrients is caused by the high population density and the absence of water treatment plants for industries. There are three major cities by the upstream of the Saguling dam, i.e. Bandung, Cimahi, and Padalarang. These cities have a relatively large number of industries, while the country-side has a dense population. The effluent of the cities, villages and industries are discharged into Citarum river and enter the Saguling reservoir.

The approximate inputs of N and P are respectively 2675 ton/year and 1391 ton/year.

Aquatic weeds

There are several species of aquatic weed occuring in the reservoir, i.e. waterhyacint (*Eichornia crassipes*), water lettuce (*Pistia stratiotes*), *Salvinia mollesta, Azolla sp.,* and *Hydrilla verticillata* . The aquatic weed may reduce the reservoir storage capacity, increase the evapotranspiration, decrease the potential of fisheries and tourism development, and may become the habitat of mosquitoes.

Land use in the watershed

Land use is a *primary indicator* of the extent and degree of the impact man has made on the surface of the earth. It reflects political, social, and economic aspects of human cultures and provides an index of the intensity of human life styles.

The relationship between land, soil, and physical conditions on the one hand and the human activities on the other may be used to evaluate land use conditions. These relationships could be studied through the changes of land use patterns, that may occur in a certain period.

Table 11.2
Land use in the site of the Saguling project.

Type	Year									
	1943[1]		1969[2]		1970[3]		1972[4]		1976[5]	
	ha	%	ha	%	ha	%	ha	%	ha	%
1. Forest	ns		221.3	10.7	97.7	4.7	90.8	4.4	90.8	4.4
2. Shrub	ns		-	-	64.8	3.1	50.7	2.8	88.9	4.2
3. Dry field	1302.3	86.9	155.0	7.5	423.6	20.4	481.1	23.2	473.1	22.8
4. Degraded land	ns		53.8	2.6	-	-	-	-	-	-
5. Mixed garden	ns		1424.3	68.6	1074.4	51.6	992.4	47.8	974.5	47.0
6. Rice field	245.6	11.0	183.0	8.0	370.6	17.9	402.5	19.4	398.6	19.2
7. Settlement	27.5	1.3	37.5	1.8	47.7	2.3	49.8	2.4	49.8	2.4
Total	2074.8	100.0	2074.8	100.0	2074.8	100.0	2075.3	100.0	2075.7	100.0

Source
1) Topographic maps of 1943 in scale of 1 : 50,000
2) Land use maps of 1969 in scale of 1 : 50,000
3) Aerial photos of 1970 in scale of 1 : 17,500
4) Aerial photos of 1972 in scale of 1 : 20,000
5) Aerial photos of 1976 in scale of 1 : 15,000

ns = not shown

The result of aerial photo interpretation and ground observation, supplemented by relevant available maps, concerning the change of land use is presented in Table 11.2. There were dynamic changes within the sample area during the period 1943-1976. The forest area is reduced from 221.3 ha in 1969 to 90.8 ha in 1976, i.e. less than 50% remains, shrubs, however, have slightly increased.

Consequently, part of the forest have been changed to other forms of land use. The decrease in forest area and increase in dry fields are detrimental to the conservation of soil and water. These changes show that the population pressure on the land resources is increasing.

Demography

a. Distribution and desity

Distribution and density of the population in the watershed is not equal. The highest density is found in a more urban district of Kertamulya (3,541 people/sq.km). If we move towards the center of the country and away from the economic activities, the density decrease to 332 people/sq.km in Gununghalu (Table 11.3).

Table 11.3
Population pressure in each district in Citarum watershed

No District	Population a)			Farmers b)				Population Pressure	
	Total	Density sq.km	Growth rate	Total	%	Agricultural land c)	"z"	1983	2000
1. Ciwidey	75 818	487	1,75	34.047	45	4.251	0,48	3,84	5,15
2 Ps Jambu	45.626	1 233	3,11	23.392	51	3 790	0,52	3,21	5,40
3. Pangalengan	102 383	215	1,94	35 716	35	9 417	0,53	2,01	2,79
4 Pacet	52 394	956	2,76	33 651	64	4 281	0,52	4,10	6,50
5 Paseh	60.972	1 292	0,89	21 893	36	3 237	0,48	3,25	3,79
6. Cicalengka	75 425	881	5,10	33 453	44	6.550	0,58	2,96	6,90
7 Rancaekek	59.140	1 285	1,45	27.482	46	4.368	0,36	2,26	2,89
8 Hajalaya	124.687	2 696	2,56	23 381	19	4 298	0,46	2,50	3,84
9 Ciparay	125 050	1.276	3,86	27 923	22	10.567	0,51	1,35	2,57
10 Banjaran	104.015	1 111	2,96	44.192	42	7 201	0,48	2,95	4,84
11. Pameungpeuk	89 877	1 544	1,29	39 289	44	5 396	0,48	3,49	4,34
12 Soreang	78 857	1.187	2,40	37.901	48	6.675	0,54	3,07	4,59
13. Cililin	104 809	646	0,76	75 566	72	9 949	0,57	4,33	4,92
14. Sindangkerta	40 301	540	0,48	25 500	63	4 642	0,54	2,97	3,22
15. Gununghalu	84 781	332	2,00	.	.	7 692	0,54	.	
16. Batujajar	56 742	906	.	24 800	44	4 424	0,58	3,25	.
17. Dayeuhkolot	133 780	5.009	5,33	10 690	8	1 768	0,35	2,12	5,12
18. Ujungberung	118 280	1 869	4,45	26.872	23	6.080	0,53	2,34	5,22
19 Buah Batu	102 748	1.626	4,30	14 472	14	2 493	0,44	2,55	4,79
20. Cicadas	93 479	1.739	4,68	17.475	19	4.158	0,60	2,52	5,48
21. Lembang	84 876	820	3,10	27.246	32	9 194	0,62	1,84	3,09
22 Cisarus	76.935	1 093	2,35	47 065	61	6.218	0,62	4,69	6,96
23. Padalarang	72 259	1.475	0,72	25 774	36	4 259	0,53	3,21	3,63
24 Cipatat	60 515	586	2,69	34.570	57	5 650	0,56	3,42	5,37
25. Cipeundeuy	50.583	417	0,97	.	.	21.096	0,62	.	.
26. Cikalongwetan	67 604	593	2,45	40.694	60	11 389	0,60	2,14	3,23
27. Ibun	41.740	800	0,96	21.026	50	2 756	0,51	3,89	4,58
28. Katapang	45 638	2 236	1,47	22 607	50	2 051	0,38	4,20	5,38
29. Cikancing	34 527	831	5,02	20.541	59	3 625	0,59	3,34	7,68
30. Ngamprah	57 321	1 600	4,60	13 608	24	1 985	0,52	3,56	7,65
31. Cipongkor	53 001	874	0,83	43 758	83	5.032	0,57	4,96	5,71
32. Kertasari	45 404	422	2,29	10.596	23	2 741	0,63	2,44	3,58
33. Margansih	48.864	2 331	1,68	19 258	39	1 056	0,53	9,66	12,82
34. Cimahi Selatan	86 220	5 048	.	3 487	4	1.037	0,56	1,88	.
35. Cimahi Utara	59 882	4.038	2,96	7.723	13	715	0,49	5,29	8,69
Bandung	2 717 344	915	3,31	1 088 719	40	197 310	0,55	3,03	5,27

a) Source: Statistical Office, Bandung, 1983.
b) Agricultural Census 1983.
c) Source: Agricultural Services, Bandung, 1983.
d) Calculated based on mathematical model: $PP_t = (fP_0 (1 + r)^t) / L$

b. Population composition

In Saguling area 66.1% of the population is in the working group age (10-64 years). The figures for the unproductive age are 30.3% at the age 0-9 years and 3.7% at the age 60-80 years.

The population composition according to the source of income shows that the majority of the population subsists from agriculture, viz. as farmers 33.5% and as farm labourers 23.3% or a total of 56.6%. From the working class, 33.5% were considered to have no skills and only little education.

c. Socio-economic condition

This aspect will in particularly concentrate on the landownership, since the majority of the population in the rural area are of farmers who make their living from agriculture. Landownership in Java is in average 0.6 ha/family. Very seldomt a farmer owns more than 5 ha of land.

Table 11.4 shows the allocation of landownership. Most farmers own than 0.5 ha of land (about 77% of the total) and their income is very limited. To fulfil their requirement for food, they either have to extend the land or to emmigrate to the cities.

Table 11.4
Number of farmer families according to the extent of landholdings in Bandung regency

No. Range of landholdings	Village		City		Total	%
	Total	%	Total	%		
1. Less than 0,05 ha	25.011	10,22	3.007	11,72	28.018	10,36
2. 0,05 - 0.09 ha	34.899	14,26	3.700	14,42	38.599	14,27
3. 0,10 - 0,24 ha	75.037	30,66	7.441	29,00	82.478	30,50
4. 0,25 - 0,49 ha	53.341	21,80	5.746	22,39	59.087	21,85
5. 0,50 - 0,74 ha	23.805	9,73	2.318	9,03	26.123	9,66
6. 0,75 - 0,99 ha	11.350	4,64	1.032	4,02	12.382	4,58
7. 1,00 - 1,99 ha	15.068	6,16	1.587	6,18	16.605	6,16
8. 2,00 - 2,99 ha	3.954	1,62	474	1,85	4.428	1,64
9. 3,00 ha and more	2.274	0,93	354	1,38	2.628	0,97
Total	244.739	100,00	25.659	100,00	270.398	100,00

Source: Agricultural Census, 1983.

11.5 ENVIRONMENTAL PROBLEMS IN THE DEVELOPMENT OF THE DAM

The impact of the dam is considered from two angles, i.e.

1) **Project impact on environment**, and
2) **Environmental impact on the project**.

The first one is normally considered in many environmental impact assessment studies, but the second is often neglected. It is, however, important, particularly in developing countries, where development projects are needed to increase the living standard of the population to prevent further environmental deterioration.

Based on the identification of potential impact and estimation of the importance of the impact, priority should be given to two aspects, i.e. resettlement of the displaced population and the population pressure at the upper catchment area, which causes high erosion rates.

1. Project impact on environment

Impact on the human population

The number of people previously living in the inundated area were 13,737 (2,974 families). Only people living in the proposed inundated areas are usually considered for resettlement, while people affected outside the inundated areas are often neglected. This is particularly people who live above the high water line (HWL) of the reservoir and who are entirely or to a certain degree making their living from the proposed inundated area.

Table 11.5
Dependency of income of people living above the HWL on resources below the HWL

Level of dependency	Landowner		Farmlabourer		Total	
	No. of families	%	No. of families	%	No. of families	%
< 25	1,780	28	419	33	2,199	29
25 - 49	2,733	43	432	34	3,165	42
50 - 74	1,525	24	267	21	1,792	23
> 75	318	5	152	12	470	6
Total	6,656	100	1,270	100	7,626	100

Table 11.5 shows the level of dependency of income for people living above the HWL on the resources below the HWL in the Saguling project. It shows that about 70% of the total number of families depend for 25% or more of their income on resources below the HWL. Before the project, 72% of the total number of families had a standard of living above the poverty line (Table 12.6). But if the income from resources below the HWL is lost without

compensation from alternative sources, only 45% of the total number of families will maintain a standard of living above the poverty line. In absolute term this would mean a decrease from 5491 families to 3433 families or 2058 families more would have a standard of living below the poverty line. Evidently, measures must be taken to solve this problem. In Saguling, therefore, the number of families to be considered for resettlement would not be only 2947 families, but approximately 10,000 families, or total of about 50,000 people.

Table 11.6
Standard of living for people above HWL who are dependent on an income from resources below HWL

	Based on total income				Based on income from resources above HWL only			
	Above poverty line		Below poverty line		Above poverty line		Below poverty line	
Level of dependency	No. of families	%	No. of families	%	No. of families	%	No. of families	%
< 25	1,678	22	610	8	1,526	20	726	10
25 - 49	2,288	30	762	10	1,601	21	1,449	19
50 - 74	1,220	16	458	6	306	4	1,372	18
> 75	305	4	306	4	-	-	611	8
Total	5,491	72	2,136	28	3,433	45	4,194	55

2. Environmental impact on the project

Population pressure on land

The population pressure on land plays an important role in the watershed management.

a. System ecology of the watershed

The watershed ecosystem may be divided into three major subsystems, i.e. the upper, middle and lower watersheds. The components in each subsystem are different. The upper catchment area is normally the most important part, since it may protect the entire watershed, particularly in term of its hydrological function. The upper catchment area should therefore be given a high priority in the management of the watershed.

The rural areas of West Java, consist of four major components (Soemarwoto, 1974), i.e. the villages (as human settlement), the agricultural areas, the rivers, and the forests (Fig. 11.2). There are interactions among the components of the system. The change of one component will affect the other components, and subsequently it will affect the function of the entire ecosystem.

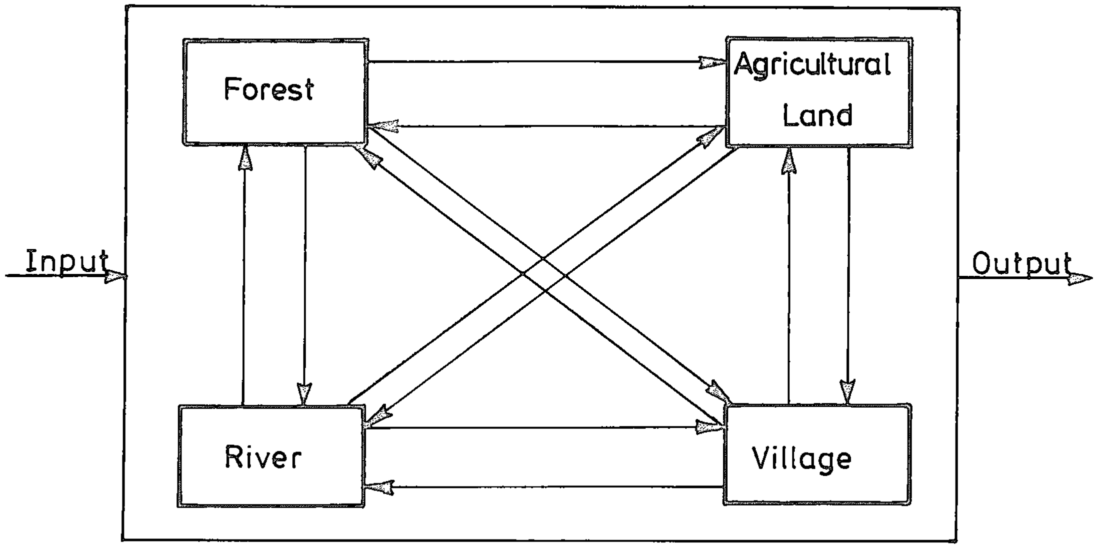

Figure 11.2 Schematical presentation of the rural ecosystem with its components. The arrow indicate the interaction among the components.

Recently, there has been a rapid increase of the population in the villages, while as mentioned above the majority of population (about 70%) are living in the rural areas and have agriculturally based activities as farmers or agricultural labourers. This means that the availability of land per person has decreased or there is an increasing demand for land. In most cases, this demand is met by forest clearing or planting in of other marginal lands such as steep terrains or slopes.

b. Population pressure

The population pressure on land is a major problem in many developing countries. Various environmental problems such as deforestation, soil erosion, drought and flood, have arisedon account of this pressure. The population pressure forces the farmers in rural areas to increase the amount of land under cultivation to meet increasing demand or it forces the farmers to give up their farming to find an income elsewhere.

Population pressure may be measured quantitatively. The mathematical model of population pressure is developed by Soemarwoto, 1984, 1985). The summary of the model may be presented as follows: Suppose an individual farmer needs "z" hectares of land for living (it is a standard of living which he perceives to be adequate. This criteria is very subjective and would differ from one person to another). According to Sayogyo (1978) the poverty line is income equivalent to 320 kg of rice/person/year. It is considered that a reasonable living is equivalent to an income twice the level of poverty line, or an income equivalent to the value of about 650 kg of rice/person/year. The percentage of farmers in the area is "f", the total number of population is "P", the annual growth rate is "r", and the total agricultural land holding is "L" hectares, "a" is the proportion of income from non-agricultural sectors, while "b" is proportion of benefit of land enjoyed by the farmer. Based on the above parameters a formula of population pressure, "PP", for time "t", can be set up:

$$PP_t = (1 - a)\ z\ \frac{f\ P_0\ (1 + r)^t}{b\ L} \qquad (11.1)$$

Population pressure is as seen dimensionless. If population pressure is "1", there is no population pressure problem, since the average land ownership is z hectares equal to the land required for a reasonable living. If population pressure is "3", the farmers are forced to expand their agricultrual land to three times their present area. Mathematically, population pressure can be less than 1, but it has no interest.

Using the equation of population pressure (PP), we can calculate the population pressure in all districts (kecamatan) of the upper catchment of the Citarum river, see Table 11.3. The calculation is made for the years 1983 and 2000. As shown in the Table the average population pressure of the upper catchment of the Citarum river (included in Bandung regency) is in average 3,03 in 1983 and will be 5,27 in the year 2000, if no measures are taken.

The study of the extent of dense forest in the Citarum watershed (Soemarwoto et al., 1976), compares the landuse map from the Directorate of Agraria of the Ministry of Internal Affairs, published in 1972 (but based on the 1969-1971 data) with ERTS satelite pictures 1972; the result shows that the rate of deforestation has been very high. 33.7% of the forest has disappeared (Figure 11.3).

Such deterioration of the forest has resulted in disturbing the hydrological function of the watershed as it has been explained above.

This means that population pressure on land in the area has already been very high and should be seriously considered.

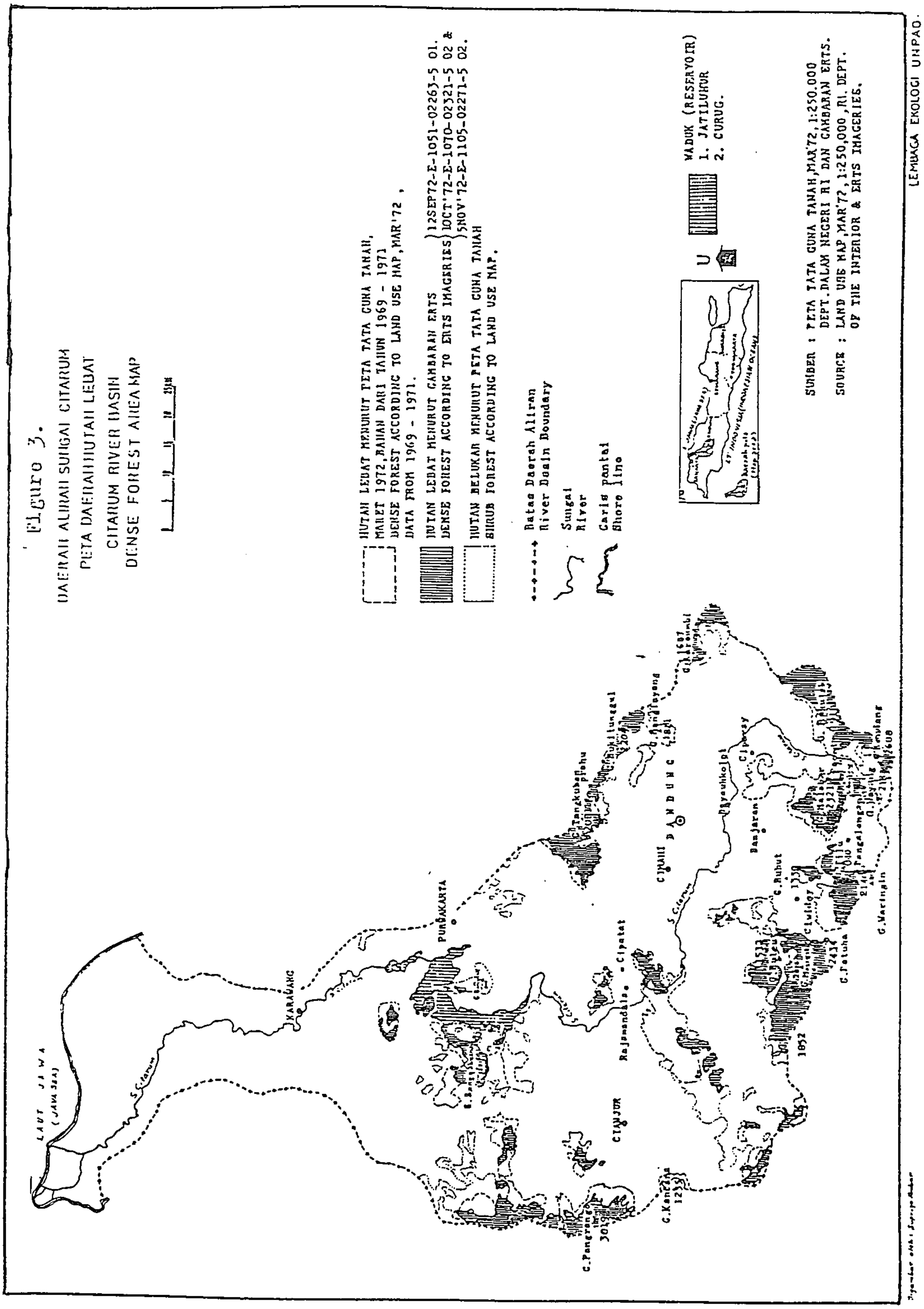

Figure 11.3: Watershed.

11.6 MANAGEMENT OF IMPACTS

The management is very complex, since it is a densely populated area, where the environmental quality of the river and watershed is deteriorating.

1. **Resettlement of the displaced people**

The study reveals that only a small number of people (3.8%) were willing to emmigrate from Java. Therefore, efforts have been made to find alternatives for resettlement. In addtion, the people living above the HWL should also be considered in the resettlement plan (providing new job opportunities).

The watershed is already densely populated and the land available for the resettlement of the displaced people is limited. The study proposed several alternatives of resettlement for the displaced people:

1. **Emmigration**
2. **Absorption in the construction of the project**
3. **Resettlement in the Nucleus Estate Small Holder (NES) programs**
4. **Development of agri- and aquaculture**
5. **Fisheries:** lake capture fishery, lake aquaculture, and running water fishery, and
6. **Own choice**

These recommendations were later adopted as a resettlement policy by the provincial government of West Java, and for executing this program, a Resettlement Coordinating Board was established.

Conseptually the resettlement program is geared to the development which follows the construction of the reservoir. Potential development projects are tourism, industries (e.g. food industry) and their multiplying effect. For this purpose, it is essential that part of the generated electricity should be used in the area. In other words, the dam project should support a development of the area. It is also recommended that electric energy should be utilized in the upper river basin for the creation of non- agricultural jobs to reduce the population pressure as an effort for the rehabilitation of the river basin. The conceptual framework of the resettlement program and rehabilitation of the upper river basin is shown in Fig. 11.4.

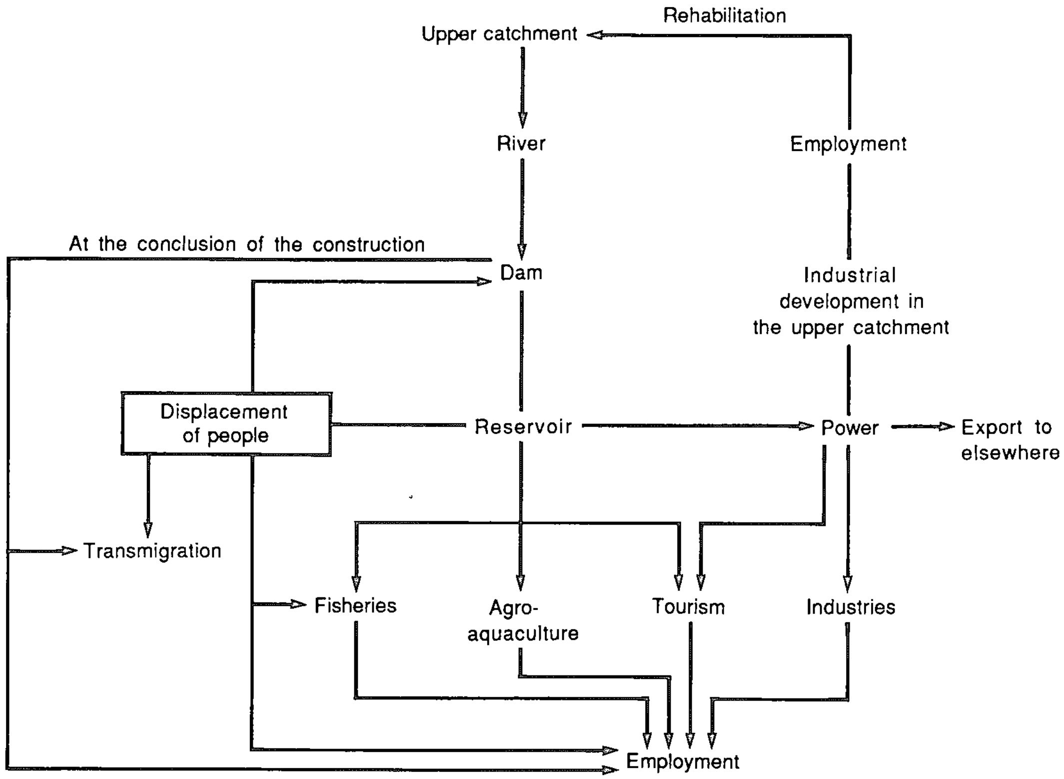

Figure 11.4 Schematic presentation of the resettlement alternatives in a dam project. The power generated by the dam is partly utilized to improve the environmental quality of the area of the dam and the upper catchment.

2. Development of aquaculture

Among the above mentioned alternatives for resettlement of the people, development of aquaculture and its multiplying effect is presently still in progress of study and implementaion.

The establishment of the reservoir has caused the inundation of human settlements and extensive agricultural land, but on the other hand another resource is established in form of a reservoir or a lake. That is why, another strategy should be developed to utilize the new resource, i.e. the lake. Utilization and development of the lake can be used to provide new jobs for the people living in the surroundings of the lake. This opportunities are particularly fishery, aquaculture and agri-aquaculture. The availability of electricity and the tourism, may gear the development of other sectors.

3. Source of feed for aquaculture

To increase the benefit of the aquaculture, it would be most favourable if the fish feed can be provided locally.

It is essential to have reliable and cheap source of feed. Ideally the feeds should not compete with food for the people, i.e. they should consist of materials which are not or rarely eaten by humans or are wasted.

Aquatic macrophytes are considered, e.g. water hyacinth (*Eichornia crassipes*), water lettuce (*Pistia stratiotes*), duckweed (*Lemna perpusila*), and *Spirodela polyrrhiza,* and leaves of terrestrial plants such as turi (*Sesbania grandiflora*), ipilipil (*Leucaena leucocephala*), *Bauhinia purpurea*..

Animal protein as feed is more essential. Currently, low quality dried fish is used, but some very poor people still use it as food. The following sources are being considered: wastes from the processing of fish, rabbits, marmot (guinea pig) and frogs, pupae of silkworms, snails and earthworms.

Rabbits and marmots are known to be reared by villagers in the Saguling area. But, consumption of their meat is very minimal, because few people like it. They are mostly used to produce "dung" which is applied as manure. Rabbits and marmots feed on weeds. Therefore, their feed as well as the use of their meat for fish feed, would not compete with human food production and consumption. The skin of these animals can be processed for the production of handicraft.

Earthworms can feed on compost which is produced from the wastes of livestock (including rabbits and marmots). The worms could be used to feed livestock and fish.

Snails have been grown on plant wastes for export. In Saguling the meat could be used for fish feed, or for export.

Frogs have been collected for the production of froglegs. The technique of frog cultivation is still in its infancy and research is needed for further improvement. The wastes from the processing of froglegs could be used for fish feed. The skin of frogs may be processed for handicraft.

Silkworms are raised in Indonesia for the production of silk. They are fed on the leaves of mulberry. The pupae in the cocoon are waste and may be used for fish feed, while the wastes of the silkworms can be composted to grow earthworms.

A scheme of overall integrated system consisting of various possibilities and components is shown in Fig. 11.5. It shows a recycling system producing fish, meat, leather, handicrafts, silk and also reducing environmental pollution. Biogas can furthermore be produced in this system, if desired. Research and experiments are still in progress to determine which of the components are technically and economically feasible in the area and to optimize the system.

The production could be made by the farmers themselves, i.e. in an integrated farming system as shown in Fig. 11.5 or people may be specialized in production of fish only. In both cases new job opportunities would arise. Studies are still in progress in order that the new jobs would provide adequate income for a reasonable living standard.

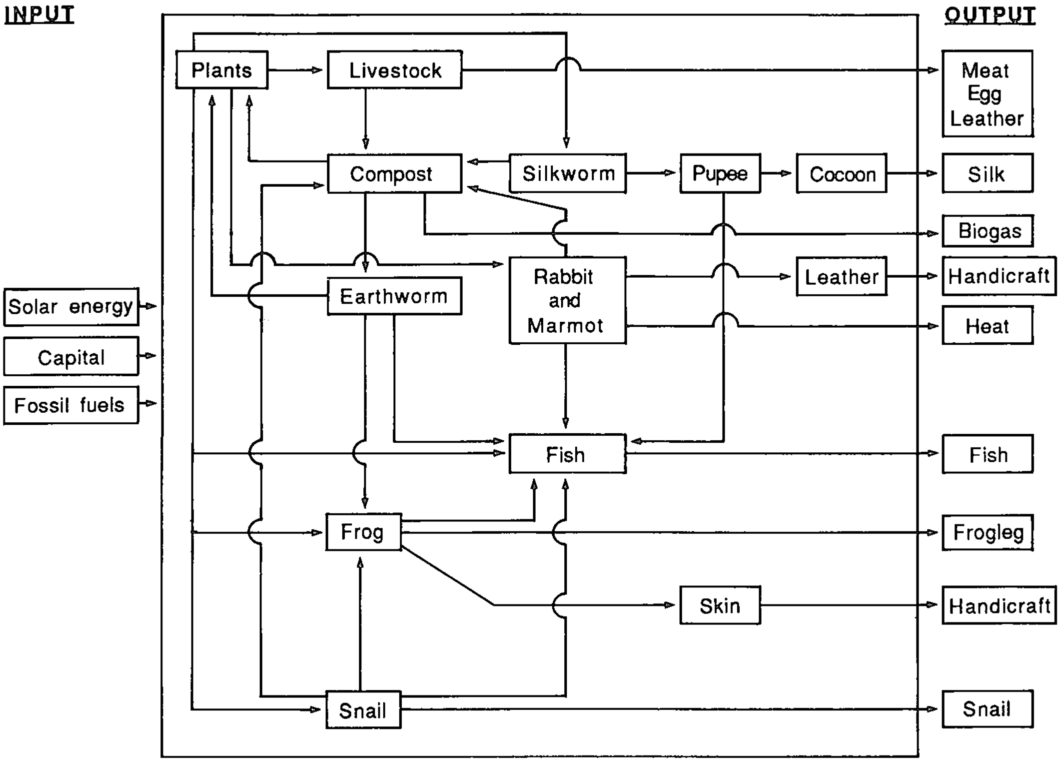

Figure 11.5 Scheme of integrated system of fish - livestock - frog - snail - silkworm and earthworm. Explanation in text.

The preliminary experimental studies which have been carried out revealed that not all animal species may develop well. Present emphasis is given on rabbits, earthworm, and *Tenebrio molitor* which have shown promising prospects, while cultures of the other species will be realized later. Preliminary experiment show that, rabbit meat and earthworm mixed give the same growth of the fish (*Cyprinus carpio*) as commercial fish feed.

4. Model of population pressure and its application in environmental management of the Saguling project

The utilization of the above resource can reduce the population pressure of the area. By development of aquaculture, the value of "z" is minimized. From calculation based on statistical data of net income from respective landuse (BPS, 1982) and from the recent studies done by the Institute of Ecology, the value of "z" for various farming systems are presented in Table 11.7.

Table 11.7
Average minimal hectarage of land for a perceived adequate standard of living of (z)

No.	Farming type	z (ha/person)
1.	Wet rice	0.50
2.	Upland crops	
	- corn	1.57
	- cassava	0.54
	- sweet potato	0.60
	- peanut	0.45
	- soybean	0.61
	Average upland crops	0.75
3.	Silkworms	0.39 - 0.78
4.	Fresh and brackish water fishpond	0.19
5.	Running water fisheries	$4*10^{-4}$
6.	Floating net fisheries	$16*10^{-4}$
7.	Orchids	4 to 60 $*10^{-4}$
8.	Chicken eggs	10 to 36 $*10^{-4}$
9.	Rice - rice	0.30
10.	Rice - rice - fish	0.24
11.	Rice - fish - rice - fish	0.18
12.	Rice - (cucumber + elck plant)	0.23

Note: i) The perceived adequate standard of living is here assumed to be twice above the poverty line, i.e. 650 kg rice/person/year

ii) No. 1 and 2 calculated from statistical data of the Central Bureau of Statistics (1982); No. 3 to 8 from resettlement studies of Saguling (Institute of Ecology, 1982); No. 9 to 12 from studies of Cirata (Institute of Ecology, 1985).

It is clearly shown that the value of "z" for agriculture is relatively high, i.e. 0.5 ha/person for wet rice and 0.75 for upland crop for a person to have income equivalent with 650 kg rice/year.

If fisheries are developed in the area, it will need much smaller area to have income equal to standard of reasonable living. Calculation shows that "floating net" may give high yield, and only 16 sq.m/person is needed. So, the value of "z" for floating net is very small. Other alternatives which have small value of z may also be developed, e.g. running water fisheries (z = 4 sq.

mt), chicken eggs (z = 10-36 sq.mt), and others.

The value of "f" or proportion of farmer population can be reduced accordingly if the development of non-agricultural sectors can be accelerated (such as development of fisheries), i.e. by work which is connected with the development of fisheries. But it should be emphasized that the effort to create such job must consider that they should be given to the poor and displaced people. So, the industries should not require high capital investment, but rather be absorbing a *large number* of the poor population.

The value of "r", or the rate of farmer population growth, must be reduced. This could be done by a family planning program. The increase in standard of living may also have a positive effect to the reduction of population growth (Pirie, 1984).

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APPENDIX

AN INVESTIGATION FLOW CHARTS

The aim of the flow charts is to show which rather simple measurements and samplings have to be done and which factors have to be considered to get information of structure and function of an ecosystem.

I. Basic data

(vertical profile in the deepest part of the lake)

1. Water temperature (thermistor)
2. Dissolved oxygen (Oximeter, Winther methods)
3. Light penetration (Secchi disc, light meter)
4. Conductivity
5. pH
6. Water samples (P-inorganic, Nitrate, Nitrite, Ammonium)
7. Vertical plankton haule
8. Primary productivity.

These basic data are strongly influenced by the following climatic factors acting as forcing functions:

- solar radiation
- wind
- air temperature
- precipitation

II. Sediment

Sediment core
Sediment sample

III. Inputs from the watershed

Depend on land use: arable land
forest

Morphology of the landscape
(steep slopes with increasing run off of nutrients)

Drainage system type

Ratio area lake/area watershed

IV. Lake morphometry

Depth (max) Z_{max}

Depth (mean) Z

Morphology of the lake basin.

From these data we get important information, e.g.

Temperature: Depth of thermocline (Epi-, hypolimnion)

Oxygen: Aerobic - anaerobic zone

Light: 1% light = boundary of zone of primary production

Conductivity: Hardwater - softwater lake

pH: Acidification, special environmental conditions

Nutrients: Eutrophic or oligotrophic conditions. Particularly important in determination of P and N-compounds after the fall turnover for measuring the complete nutrients standard available for future production.

Wind: Influences strongly the stability and position of thermocline, which acts as a physical boundary between the basic compartments epilimnion/hypolimnion.

Precipitation: Has great influence on the stratification and stability of the lake.

Morphology: In shallow lakes the mud-water exchange of nutrients can strongly influence the nutrient supply of the lake: shallow lakes are productive.

Sediment: Anoxic black sediment (H_2S) has a great exchange of P with the overlying water, P is fixed by iron or manganese.

Watershed: High loading water from arable land, with steep slopes after fertilization. Woodlands and wetland are trapping the nutrients.

Phytoplankton: Waterbloom, esp. blue-green algae, are indicating high productivity.

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