DRAFT PAPER

INSIGHTS INTO INDONESIAN LAKES
Features Important to Observe in Management

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Lake Tamblingan, Bali

Foreword

Research of Indonesian lakes shall be a devotion, not a duty. It is an adventure, which cannot be shared with anybody else except those who participated in the adventure. I have experienced great moments in developing the project and equipment to study the lakes and wandering across Indonesia with the team studying lakes, which have never before been studied down to their greater depths, got life-long friends of colleagues and local people, and been satisfied of the work done. The primary driving force has been the desire to learn more.

The president of the International Association of Theoretical and Applied Limnology (SIL) highlighted in her presidential address to the SIL 28th congress in Melbourne in 2001 by saying: "The small numbers of papers about tropical inland waters published highlight the enormous value of the four volumes of Limnology in Developing Countries published by SIL. Many of the developing countries are in the tropics. The authors and editors of these volumes deserve thanks and congratulations of the international limnological community".

According to the editors, data in one of the papers, Limnology in Indonesia, from the legacy of the past to the prospects for the future (Limnology in Developing Countries, Vol. 2:119-234, 1999) are surprisingly large for the tropics. The author of this paper together with Badruddin Machbub, Nana Terangna, Firdaus Achmad, Lusia Boer, Simon Sembiring Brahmana, Bambang Setiadji, Bambang Priadie, among others, prepared the paper.

However, it is not enough. The majority of lake studies are momentary records, snapshots, which describe only the net effects of continuous processes and metabolism. The step from water as a substance and its extents, concentrations, biodiversity and biomasses to processes of hydrodynamics and rates of assimilation and decomposition has yet to be taken in Indonesia. Dynamic dimensions need to complement static variables. What seemed self-evident to a scientist from the north has become a problem and general concepts like production appear now in an entirely new light. Many vital issues of humankind are located in tropical areas, where water and water conditions, including lakes, represent one of the prime prerequisites for survival and coexistence.

The above should be a clear road map of the direction to proceed for informed decision-making and state-of-the-art management of Indonesian lakes and lake basins, rather than relying on know-how and direct technology transfer practiced by developed countries.

Pasi Lehmusluoto

Introduction

In the large island nation of Indonesia, inland waters cover a total of 534,500 square kilometers, of which swamps 394,000, rivers and floodplains 119,500, man-made lakes 16,000 and natural lakes 5,000 square kilometers. Irrigated areas can also be considered as "shallow lakes", which occupy large areas. There are *521 natural lakes*, the greatest number of lakes within Southeast Asian countries, and 14 of them are over 100 m, 8 over 200 m and 3 over 400 m deep, and over 100 reservoirs. In the entire world, there are only 20 lakes over 400 m deep. The lakes contain some *500 cubic kilometers of freshwater*, largest volume of lake water among Southeast Asian countries.

The nation-wide long-term, in-depth information of the Indonesian lakes is limited. The short-term *Sunda Expedition* visited lakes in Java, Sumatra and Bali in 1928-1929 and sporadic, time, area and depth limited and narrow studies governed the 1970s, 1980s and 1990s. The *Expedition Indodanau* of the then PU, presently Kimpraswil, covered major lakes and reservoirs in Sumatra, Java, Bali, Lombok, Sulawesi and Irian Jaya in 1991-1994. LIPI Limnology, SEAMEO-BIOTROP and some universities also study the lakes.

The inland waters - *fresh and saline natural lakes, reservoirs, floodplain lakes, wetlands, swamps, rice fields and rivers* - are large resources for a multitude of benefits. They are valuable storehouses of water and biodiversity with a number of endemic species, effective in preventing floods, important ecological entities and sources of food. They supply water for people, sanitation and water carriage sewerage, and trade and industry, support economic livelihoods like fisheries and aquaculture, hydropower generation, irrigation, transport and recreation and tourisms, and are important for religious ceremonies and the uses of the nature

itself, of course. For indigenous waterfront communities they provide foundation for livelihood. However, population pressure, development activities and transition of society from an agricultural country to an agro-industrial nation, usually synonymous to progress, threaten lakes at the expense of their ecological sustainability.

Features of Lakes

Physically speaking, the Indonesian lakes are characterized by the *small seasonal variations in temperature*. This is an obvious consequence of the small variation of solar radiation input. In general, the daytime surface water temperature is high but can be quite low at high altitudes, ranging from over 30 to below 20 Celsius degrees. Typically, the annual variation range of surface water temperature is 2-3 Celsius degrees. One consequence of the *small vertical temperature difference* is that lake area and winds, which tend to be seasonal, are important driving forces in hydrodynamic events in comparison to temperate lakes. However, in the higher temperatures even small temperature differences cause greater density differences than in temperate lakes making tropical and Indonesian lakes quite stable. Such lakes have often caused confusion and local scientists have erroneously identified them as homotherm and holomictic. The small seasonality in temperature implies also a *low value of the annual heat budget* of lakes. The relative variation of this budget in consecutive years may be considerable, because the peak value of heat storage may result from a single meteorological event. In general, the wind velocity is highest during the dry season and tends to maximize evaporation in dry months. The resulting heat losses and turbulence enhance water mixing during this period. The major characteristics contrasting temperate and tropical lakes, excluding shallow lakes, floodplains and wetlands are shown in Table 1.

Table 1. Characteristics contrasting temperate and tropical lakes, excluding shallow lakes, floodplains and wetlands.

Characteristic	Temperate Lakes	Tropical Lakes
Watershed area compared to lake surface area	Large	Small
Water level fluctuation	Minor	Major
Water residence time	Short	Long
Annual temperature variance	High	Low
Vertical temperature difference	10-30 Celsius degrees	2-3 Celsius degrees
Polymixis	Uncommon	Common
Dimixis	Common	Uncommon
Monomixis	Uncommon	Common
Oligomixis (atelomixis)	Uncommon	Common
Meromixis	Uncommon	Common
Reactive and metabolic rate	Low	High
Decomposition rate	Low	High
Amount of dissolved organic matter	High	Low
Amount of organic compounds	High	Low
Phytoplankton	Relatively rich	Relatively poor
Zooplankton diversity	Relatively rich	Relatively poor
Fish diversity	Relatively rich	Relatively poor

The strong seasonal variation of precipitation may lead to a water level variation of several meters in tropical lakes. This has a considerable impact on water dilution and nutrient supply especially in smaller lakes. The seasonality of precipitation also essentially affects such biological events as algal blooms, zooplankton reproduction and fish spawning. The traditional *classification of lakes based on the seasonal temperature variations at different depths, i.e. on stratification/mixing pattern is not adequate in the tropics and Indonesia*. Lake *typology should be based on rates of productivity, the rate of organic matter supplied by (autotrophy) and/or to (allotrophy) the lake and decomposition, i.e. rate of metabolism or bioactivity*. However, in the absence of such data for classification, *a more relevant classification is based on geographic features*, and classification according to the stratification/mixing pattern is shown in brackets:

- Large, deep lakes, which all have seasonal thermoclines and from a shallow to a deep, permanent chemocline, below which the water mass is anoxic. However, a mixing (circulation) of this deep water may occur, although the intervals and mechanisms are not clear. (Meromictic, Atelomictic);
- Shallow lakes, which occur both in climates with a small and a large diurnal temperature variation. The

former implies a weak stability with frequent overturns, the latter a more distinct pattern of stratification. In the latter case, nighttime evaporation losses may be considerable. (Polymictic, Monomictic);

- Very shallow lakes, with a clear diurnal temperature variation: morning homotherm conditions change to afternoon stratification, which is eroded during the night. The water level fluctuation may be considerable as compared to lake volume. This also implies the existence of large floodplains and wetlands, which may be the main factor in biological productivity. (Polymictic);
- Crater lakes, generally rather small by surface area and without inflow and outflow rivers, having great depth and a sheltered position. These lakes are often stratified and have permanent chemocline, below which the water mass is anoxic, but may undergo once a year a complete mixing due to special weather conditions like in East Java. (Monomictic, Oligomictic, Atelomictic);
- High-altitude lakes, numerous in the Andes, but are found also in East Africa, the Himalayas, Indonesia and New Guinea. They are found both in areas with small and large diurnal temperature variations. The small variation implies weak stability and frequent overturns and the latter stronger stratification and probably considerable nighttime evaporation losses. (Polymictic, Monomictic);
- River lakes, the nearby river being their main water supply during its high stage. When the river recedes, the lake water flows toward the river. This high annual or semi-annual water exchange considerably affects the chemical and biological features. (Polymictic);
- Solar lakes, saline, dark-bottomed lakes in which an anomalous stratification may develop. The lower water layer may warm very intensely by solar radiation, when it is well isolated from the atmosphere by the upper lighter brine. This process sometimes leads to water temperatures reaching 50 ^{O}C. (Oligomictic);
- Temporary lakes, in which seasonal, medium- and long-term fluctuations of water level may be so large that a shallow lake basin dries up. In regions with pronounced wet and dry seasons, this phenomenon may take place every year. It often leads to the accumulation of salts on the lake bottom. (Polymictic).

As seen above, in the tropics the *origin, altitude, size and depth of the lake and effects of wind are decisive factors in hydrodynamic events. In addition, factors like water renewal time shall be accounted for*. This makes management of tropical lakes more complex and unpredictable than temperate lakes. *Indonesian lakes can be divided into two major clusters and the clusters into sub-groups* (Table 2).

Table 2. Clusters and sub-groups of lakes, mixing types based on stratification/mixing patterns of temperate lakes, least prerequisite approach to be applied in the lake management and examples of lakes in each sub-group.[1]

Cluster/Sub-group	Mixing Type	Approach	Examples
CLUSTER A			
A. Closed lakes			
- Shallow high-altitude lakes	Monomictic	Ecosystem	Batur, Bratan
- Shallow meromictic high-altitude lakes	Atelomictic	Ecosystem	Buyan, Tamblingan
B. Open lakes			
- Very shallow low-altitude lakes	Polymictic	Ecosystem	Limboto
- Shallow low-altitude lakes	Oligomictic	Ecosystem	Rawa Danau, Tondano, Sentani
- Shallow high-altitude lakes	Monomictic	Ecosystem	Diatas
- Deep low-altitude lakes	Oligomictic	Ecosystem	Lamongan, Pakis, Poso, Towuti
- Deep high-altitude lakes	Monomictic	Ecosystem	Toba, Kerinci
- Deep meromictic low-altitude lakes	Atelomictic	Ecosystem	Maninjau, Singkarak, Matano
- Deep meromictic high-altitude lakes	Atelomictic	Ecosystem	Dibawah, Ranau
CLUSTER B			
C. Wetland and floodplain lakes			
- Very shallow lakes	Polymictic	Watershed	Sentarum, Sidenreng, Tempe
D. Salt lakes			
- Very shallow lakes	N/A	N/A	N/A
E. Man-made lakes			
- Very shallow lakes	Polymictic	Watershed	Wlingi
- Shallow lakes	Oligomictic	Watershed	Saguling, Jatiluhur, Darma, Selorejo

[1]Very shallow means less than 5 m, shallow less than 50-100 m and deep over 50-100 m deep, and low-altitude below 750 m and high-altitude over 750 m.

In broad, in managing lakes in the first cluster, which are generally starting points of rivers, "eyes of the oceans", strict ecosystem approach shall govern the activities in the lake and catchment areas. These lakes have an advantage being in the uppermost tributaries and having relatively small catchment areas: They are not subject to excess siltation and run-off containing, for example, agrochemicals. However, advanced research and continuous monitoring, and EIA-type evaluation, which integrates all expected and unexpected but known synergistic and/or antagonistic effects shall be made as a mandatory part of spatial planning and development activities. To this cluster, two exceptions shall be accepted, Singkarak and Mahalona-Towuti chain, which receive water from Dibawah and Matano, respectively. Due to long residence time of water, even if the environmentally harmful activities were reduced or fully intercepted, chances of recovery of lakes in this cluster are faint.

Lakes in the second cluster are expanding and shrinking bowls on and appendices of rivers, sometimes forming groups and chains of lakes, reservoirs included. In these lakes, increase or reduction in effects of watersheds is directly reflected in their state because water is rapidly exchanged. If all man-induced pollution were stopped today, these lakes could recover in due course, depending on various factors.

Generally*, the required level of sewage and effluent treatment and reduction of non-point run-off rises when recipient water changes from river to reservoir, open lake with short to open lake with long water residence time, and finally to closed crater lake in which water exchange happens through precipitation and evaporation, for which the highest level measures are needed*. Community-based treatment solutions applied for river discharges cannot be used, for example, for Bratan in Bali. *Generalizations in hydrodynamics, lake functions and biodiversity may lead to misconceptions and unknowledgeable management decisions*.

Upper water layers of lakes reflect the daily changes in weather and air temperature and deep-water temperatures are related to annual minimum temperatures during hemispheric winters reflecting long-term climate change, ranging from 19 to 31 ^{o}C depending on altitude. There are great latitudinal differences and in Indonesian lakes, the vertical temperature difference is only 2-3 Celsius degrees compared to the 10-30 Celsius degree difference in temperate lakes. Therefore, *due to the higher temperature, 1 Celsius degree change in water temperature causes similar change in density as 10-15 degree change in temperate lakes and the oxygen depletion rate of deep water often indicates higher rates of chemical processes and metabolism in contrast to eutrophication of temperate lakes*. In Indonesian conditions, the deep water of oligotrophic lakes may become anoxic within a few weeks, and zero nitrate state developed within a few days after anoxia.

Prevalence of anoxia in the deep water is common, associated with the presence of nutrients, carbon dioxide and hydrogen sulfide. The oxic surface water volume is often only a small proportion of the total lake volume. Good examples are the Sumatran permanently meromictic lakes. *Altitude, area, depth, hydrology, especially water renewal time, and chemistry, biology and hydrodynamic functions determine the resilience capacity*, the so-called self-purification capacity of lakes. The stratification/mixing types prepared for temperate lakes indicate the frequency of full vertical mixing of the entire water mass, which replenishes oxygen reserves and brings nutrients and other chemical compounds into the upper water layers. Compared to temperate lakes, which generally mix two times a year, the *Indonesian lakes show great irregularity in mixing, affecting oxygen replenishment of lakes*. Only the very shallow polymictic lakes mix daily but monomictic only once a year during the hemispheric winter. The other types have varying, irregular mixing intervals. Oligomictic lakes may mix occasionally in a decade and atelomictic to varying depths annually but once in a decade, century or never down to the bottom. In *the ecosystem approach, the holism of these factors decides the options and level of treatment required for sewage and effluents, and the preventive measures in the watersheds* to regulate non-point run-off from rural settlements and agricultural land (Figure1).

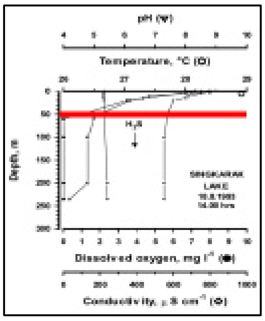
Figure 1. *Lake Toba, despite contrasting public outreach, is practically in the same state*

development, local waste dumping, discharge from lake shore
livelihoods and tourist facilities, nutrient loadin - -
- fro agricultural land.

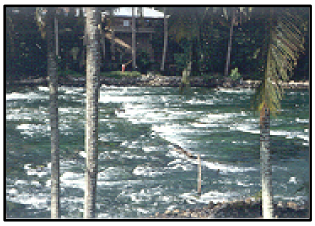
Vertical mixing of Toba, Batur, Bratan, Towuti and Poso is important in keeping them in good state. However, many Indonesian lakes are "sleeping bears" with great amounts of gases, nutrients and other

substances blocked dormant in their stagnant deeper waters. If, for some reason, natural event or mismanagement, these substances even partially mix with the upper water layers great ecological changes may happen, causing fish kills and sudden eutrophication. Such lakes are, for example, Maninjau, Singkarak, Dibawah and Ranau, and some of the crater lakes in East Java, in which the volume of anoxic water is much greater than the above oxygen rich water. In Singkarak, anoxic conditions prompt already at the depth of 40-50 meters in the 268 meter deep lake, and the anoxic water volume is 19 out of the total volume of 24 cubic kilometers, containing 60,000 tons of carbon dioxide, 18,000 tons of hydrogen sulfide, 12,800 tons of nitrogen and 1,760 tons of phosphorus. In order to make the stored hydrogen sulfide harmless, 36,000 tons of oxygen would be needed, but in the unexpected event that the deeper water masses would fully mix with the upper water, there is only 70 tons of oxygen available. Increased water withdrawal for hydroelectricity has already caused ecological changes in the lake (Figure 2). Matano is a specific case in Sulawesi (Figure 3).

(a)



(b)



(c)

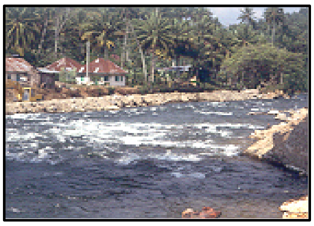
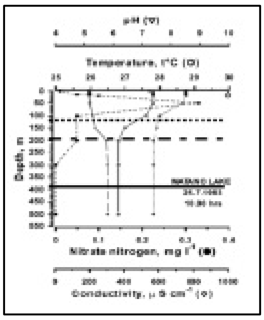


Figure 2. *Ecology of Lake Singkarak developed and stabilized during millennia having a permanent chemocline at the depth of 40-50 meters shown by the red line, which separates the oxic and anoxic water masses (a). The anoxic water mass, 80 per cent of the total volume of the lake, contains great amounts of harmful substances, including plant nutrients, carbon dioxide and hydrogen sulfide. Regardless of this fact, hydropower development was commenced in 1993, and the plant operations began later. Before the construction works in 1992, the outflow water was clear and greenish (b) but already in 1993, the color was brownish (c). The lowered riverbed and increased water withdrawal may have enhanced partial mixing of the nutrient rich deeper water with the upper water layers enhancing eutrophication and causing changes in the lake's ecology.*

(a)



(b)

Figure 3. *Lake Matano is one of the extraordinary lakes in Indonesia, the onl*
208 meters below the sea level. The solid line shows the sea level and the dotted line thermocline (a). The lake has a
species. One of the world's largest
nickel deposits surrounds the lake and the PT Inco mining and smelting operations discharge effluents into the lake (b).
he sediments are
related to ground water inputs although the PT Inco effluents contain high concentrations of nickel and zinc and plant nutrients. There is also evidence that the operations may cause acid rain deposits. Ground water is a commonly used i for

The nutrient concentrations are usually low in natural lakes in Southeast Asia, especially phosphorus concentrations, contrary to observations made e.g. in Africa and South America. Lakes get their natural nitrogen mostly with rains and phosphorus, sulfur and silicate from soil, which is usually low in phosphorus. Due to the high water temperatures, the nutrient cycling may be fast. Algal production of lakes is generally limited by nitrogen according to the studies made in Africa and South America, contrary to observations in Southeast Asia, and in sewage-loaded lakes. In Indonesia, *phosphorus limitation is common in natural lakes and this may prevent from widespread promulgation of cyanobacterial blooms but phosphorus-rich sewage and effluents may change the situation*. However, it is important to note that *eutrophication is not yet a*

common feature in Indonesian natural lakes because rapid mineralization of organic matter prevents accumulation of nutrient loaded sediments making eutrophication less irreversible than in temperate lakes. This is also evidenced by the *exceptionally low chlorophyll and phytoplankton biomass values*.

Primary productivity of Indonesian lakes, unlike in temperate ones, is not seasonally limited by low intensity of solar radiation or ice cover. The annual production in tropical lakes is higher than in similar lakes in the temperate region but, as mentioned above, in the warm water the rates of decomposition processes are maintained at a high level. It is therefore *not self-evident that the net primary production available to zooplankton, fish and other herbivorous animals is high in Indonesian lakes*. Otherwise, the fish yields would be higher than today.

There is a common perception derived from the context of rain forests and coral reefs that also the tropical lakes have higher species diversities than temperate lakes. This can well be applied for very shallow lakes, wetlands, floodplains and flooded forests but *larger Indonesian lakes cannot compete in the number of phytoplankton and zooplankton species with temperate lakes*. There are far fewer species and specimen as would have been expected. As a rule of thumb*, large and deep lakes have poorer species diversities than small and shallow lakes and wetlands, the transitional ecotones between land and water*. These areas have also the greatest productivity. However, in many lakes biodiversity has been affected by the introduced exotic species.

The erosion rates of the Indonesian river basins vary by several orders of magnitude depending mainly on rainfall and regime, land slope, degree of degradation of vegetation cover, ability of vegetation to regenerate and soil type. Highest erosion rates occur usually in mountain streams and rivers, particularly in areas, where man's influence has caused considerable destruction over vegetation (torrential rains and lahars). Indonesia is among the greatest dischargers of sediments with annual sediment transport of 3 billion tons, over 1,000 tons per square kilometer. In addition to the sediment transport, rivers are major transport routes of pollutants. However, *most of the natural lakes are located in the upper tributaries being starting points of rivers and susceptible only to localized pollution and non-point run-off*.

Management of Lakes and Lake Basins

Many *government departments and related institutions are involved in the use, management and preservation of Indonesian lake resources but none is responsible for and coordinates their management*. Capable, efficient leadership of one single institution and collegiate decision-making are different issues. It is difficult to imagine a better way to manage the natural lakes than increased knowledge, which self-evidently guides the activities necessary in their basins. The World Lake Vision: A Call to Action launched in Japan in March and promoted in Indonesian in June 2003 gives a voluminous potpourri of general information. The visions are too general, superficial and ambivalent to improve lake and lake basin management in Indonesia.

The *crucial issue in lake management is knowledge of lakes, which is the basis for the ecosystem approach and details the management requirements and options of the technological solutions*. This is complemented by capable, efficient and knowledgeable leadership of the institution responsible for integrated lake management replacing collegiate decision-making, complemented by effective law enforcement. Indonesian Lakes Forum under preparation shall transparently represent all stakeholders interested in the welfare of Indonesian lakes. Lake management is currently experiencing a period of introspection, represented by a deficiency in lake research and management. Lake management is not only a desk study and north-south process. Lake scientists and managers with practical experience of lake management in Indonesia could enhance the capacity in finding innovative solutions and increase quality and professionalism. All *planning should integrate the welfare of lakes by looking into the effects of activities in the watershed*. In the long-term, as soon as a lake, its behavior and expected responses to human activity, separated from natural "evolution", are adequately known, the ecosystem approach shall be applied.

Maintenance of watersheds affecting externally lakes and reservoirs is essential in lake and reservoir management, preservation and conservation. However, this cannot be done without the so-called ecosystem approach, which integrates knowledge of the internal characteristics and self-purification capacity of lakes and reservoirs and which regulate and limit the human activities. Ecosystems determine the level of actions needed for sustainability, both in terms of hydrology and water utilization (water supply, hydropower

generation, irrigation vs. rain fed agriculture, etc.) and ecology and resilience capacity (ecosystem services, biodiversity, fisheries, pollution, etc.).

Irrational and inefficient water use for irrigation, hydropower generation and human consumption can cause and has caused conflicts. Out of the 19 tectonic-volcanic lakes, already 10 have regulating dams. Degraded water quality and toxicity, fish kills and disease of millions of humans annually is the direct cause of pollution. Natural resources and the environment - habitats, ecosystems and species - are threatened. Many *Indonesian lakes belong to the three ecologically important categories*: 1) Lakes in transition from oligotrophic to eutrophic, naturally or human-induced, 2) Lakes with very specific characteristics of being closed volcanic, dystrophic or meromictic or saline, and 3) Man-made reservoirs and ponds. In addition, severe pollution affects most of the small lakes and reservoirs.

Expansion of knowledge needs to address the legitimate desires of the local stakeholders, livelihood, trade and industry sectors and communities as well as capacity and capability within institutions to respond to the challenges of economic and social development. Corporate responsible is one vital issue. In several occasions integrated, non-sectoral management could have given better results. *Knowledge of lakes and their functions shall be drastically increased*. To meet the targeted goals of sustainability in lake management and good ecological state of lakes, capacity development is the means for the state-of-the-art and self-reliant management of Indonesian lakes and lake basins, rather than relying on imported know-how of developed countries.

For decades, *lake management professionals have found management programmes of individual lakes the most feasible means*. At global, regional and national levels three modes are needed: 1) Inventories of regional and country level knowledge of lakes, 2) General guidelines of options for lake and lake basin management, and 3) Supplementary guidelines for lake and lake basin management for Indonesia, which scrutinize the previously described differences in temperate and tropical lakes and evaluate and advice how best to apply management options to various lake types. Although *general, global principles prevail in lake management, considering the insights presented in this paper a clear distinction has to be made between the temperate and tropical lakes and between the specific characteristics of lakes and reservoirs when applying the principles in their management.*

Indonesian researchers and lake managers are obliged to find the integrated management options to achieve and maintain good ecological state of waters and lakes and tell it to the decision-makers and general public. However, it is the *responsibility of politicians to decide what state of rivers and lakes they want to give*. Are they going to be garbage dumping sites and sewers with significant environmental evils or healthy ecological entities fully benefiting water front dwellers?

The *goal of the ecosystem-based management is the good ecological state of waters and lakes and the management options are tools to achieve the goal, not goals themselves*. For the ecosystem approach, the individual basins and lakes shall be profoundly known. *Improved ecological state of lakes is the measure of success, not improvements in wastewater treatment and reductions in sewage and effluent loads*.