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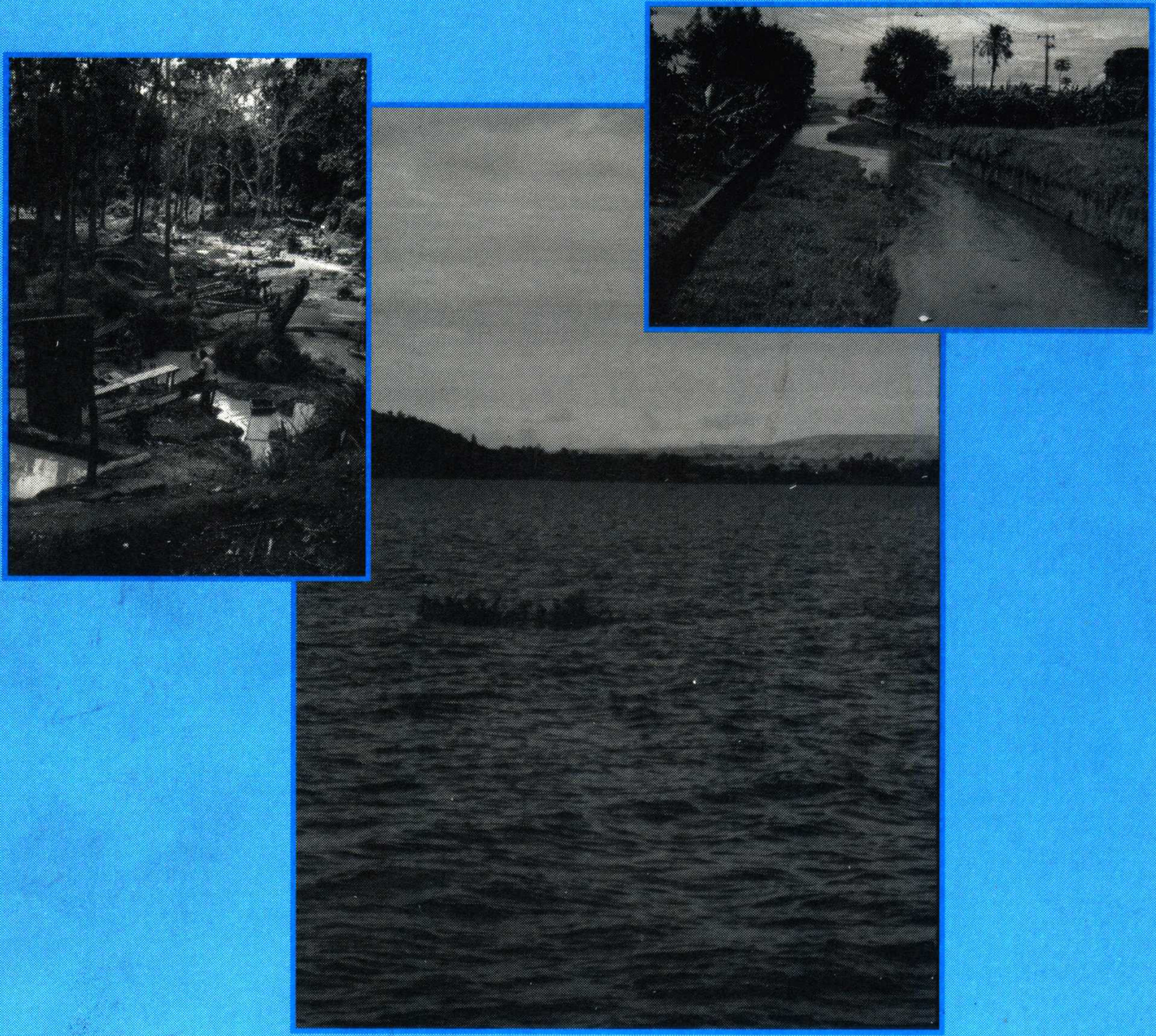
Restoring and Protecting the World's Lakes and Reservoirs

Ariel Dinar, Peter Seidl, Harvey Olem, Vanja Jorden, Alfred Duda, and Robert Johnson



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Ariel Dinar is an economist in the Agricultural Policies Division of the World Bank's Agriculture and Natural Resources Department. At the time of writing, the other authors were in the Pollution and Environmental Economics Division of the Bank's Environment Department; Peter Seidl and Harvey Olem were consultants, Vanja Jorden was a research assistant, Alfred Duda was a senior environmental specialist, and Robert Johnson was an environmental specialist.

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Foreword

With the publication of its 1993 policy paper *Water Resources Management*, the World Bank made a commitment to assist developing countries in establishing institutional frameworks and management procedures that would enable countries to utilize their water resources in an economically and environmentally sustainable manner. The impetus for the policy came from the alarming deterioration and increasing scarcity of freshwater resources around the globe. In particular, substantial lake and reservoir degradation has resulted from ill-conceived and poorly executed development practices.

This paper calls attention to the particular problems that lakes and reservoirs have suffered as a result of increased siltation, nutrient loading, toxics, habitat degradation, over-exploitation, and changes to marginal ecosystems. These changes have destroyed fisheries needed to sustain large segments of the population, removed land from traditional farming and grazing practices, contaminated groundwater supplies, and reduced economic benefits. There are sensitive links between the quality of a lake or reservoir and development of its catchment. If these links are properly identified, it provides individuals in decision making positions opportunity for taking actions to protect vital lake and reservoir resources during the design and implementation of development projects.

The paper is intended to continue a process within the World Bank, collaborating with the United Nations System and the development community, giving priority for protecting these invaluable natural resources. As first steps, the Bank's 1993 policy paper and the 1994 technical paper *A Guide to the Formulation of Water Resources Strategy* both identify lake protection as an important resource management issue.

Our hope is that this paper, in combination with the aforementioned volumes will encourage professionals engaged in economic development to adopt sound environmental practices. It identifies vital components of the water-based ecosystem requiring special consideration to maintain biodiversity, including wetlands and marginal floodplains inextricably linked to lakes and reservoirs. If we engage in the process of developing our economies in a way that appropriately considers our natural resources, our lakes and reservoirs and watersheds, these resources will be protected for future generations to use and enjoy for all of their benefits.

Alexander F. McCalla, Director
Agriculture and Natural Resources Department

Andrew D. Steer, Director
Environment Department

We dedicate this paper to the memory of our colleagues Harvey Olem and Peter Seidl who were lost in an airplane crash in Bolivia in May 1994. Both Harvey and Peter had a special love for lake ecosystems. Harvey became an internationally recognized expert in reservoir water quality management as a result of many years of work on the Tennessee Valley Authority's vast reservoir system, and his work with Nordic scientists addressing acid precipitation effects. Peter's work over many years in the Canadian Civil Service brought him to the Canadian north to assist indigenous people coping with the construction of large hydroelectric reservoir systems. Concern with the native issues of native people then brought him to the North American Great Lakes and later to Lake Titicaca between Bolivia and Peru. In May 1994 Harvey and Peter were assisting the Bolivian government with a project to improve water resources management when their airplane was reported lost on the way to Lake Titicaca. The benefits provided to man and nature from lakes and reservoirs in both the North and the South are in danger. Some ecosystems are irreversibly damaged. Harvey and Peter recognized this and contributed to early drafts of this paper. In their memory, we hope that this call for action to protect the sustainable use of lake and reservoir ecosystems will receive the urgent attention it merits.

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Abstract

Human activities are threatening the sustainable use of lakes and reservoirs around the globe. These sources of water are critical components in the ecological system. They provide habitat, sanctuary, and food for many species of fish and wildlife and are also a source of many beneficial uses for humankind. They provide drinking water; they are a source for process water to a myriad of industries, and their waters are used to generate power. Lakes and reservoirs provide food, navigation services, and recreational opportunities. Information and case studies reviewed in this paper indicate that the resource is at risk from over-enrichment, over exploitation, contamination by toxics, and water diversion for unsustainable agricultural uses. As a result, options for regional development are being curtailed, human populations are being uprooted, and future generations of people are being impacted by materials polluting lake waters. This paper calls for immediate action to reverse the degradation of these important natural resources. The paper argues that institutional processes should be developed to implement holistic, ecosystem-based, watershed-wide, stakeholder-driven strategies in order to sustain the resource. The way ahead was outlined by the World Bank in its Water Resources Management Policy adopted in 1993. The problems are so complex and the solutions require such a comprehensive approach that the World Bank, specialized UN agencies, and other international support organizations should place special emphasis on the problem. The paper calls on these organizations and governments to take necessary actions to make development activities more sustainable with regard to lakes and reservoirs.

Glossary

Aerobic	Describes life or processes that require the presence of molecular oxygen.
Algae	Small aquatic plants that occur as single cells, colonies, or filaments.
Algal bloom	A high concentration of a specific algal species in a body of water, usually caused by nutrient enrichment.
Alkalinity	A quantitative measure of water's capacity to neutralize acids. Alkalinity results from the presence of bicarbonates, carbonates, hydroxides, salts, and occasionally of borates, silicates and phosphates. Numerically, it is expressed as the concentration of calcium carbonate that has an equivalent capacity to neutralize strong acids.
Assimilation	The absorption and conversion of nutritive elements into protoplasm.
Anaerobic	Describes processes that occur in the absence of molecular oxygen.
Bioaccumulate	The process of biota to accumulate pollutants.
Biomass	The weight of biological matter. Standing crop is the amount of biomass (e.g., fish or algae) in a body of water at a given time. Often measured in terms of grams per square meter of surface.
Biota	All plant and animal species occurring in a specific area.
Blue-green algae	The phylum Cyanophyta, characterized by the presence of blue pigment in addition to green chlorophyll.
Chemical oxygen demand (COD)	Nonbiological uptake of molecular oxygen by organic and inorganic compounds in water.
Chlorophyll	A green pigment in algae and other green plants that is essential for the conversion of sunlight, carbon dioxide, and water to sugar. Sugar is then converted to starch, proteins, fats, and other organic molecules.
Chlorophyll-α	A type of chlorophyll present in all types of algae, sometimes in direct proportion to the biomass of algae.
Ecosystem	A system of interrelated organisms and their physical-chemical environment.
Embayments	Semi-enclosed shoreline areas of a lake or a reservoir.
Erosion	Breakdown and movement of land surface, which is often intensified by human disturbances.

Eutrophic	From Greek for "well-nourished," describes a lake of high photosynthetic activity and low transparency.
Eutrophication	The process of physical, chemical, and biological changes associated with nutrient, organic matter, and silt enrichment and sedimentation of a lake or reservoir. If the process is accelerated by man-made influences, it is termed cultural eutrophication.
Externality	The unintended real (nonmonetary) side-effects of one party's actions on another party that are often ignored in decisions made by the party causing the effect.
Flood plan	Land adjacent to lakes or rivers which is covered as water levels rise and overflow the normal water channels.
Hydrologic cycle	The circular flow or cycling or water from the atmosphere to the earth (precipitation) and back to the atmosphere (evaporation and plant transpiration). Runoff, surface water, groundwater, and water infiltrated in soils are all part of the hydrologic cycle.
Hypolimnion	The lower, cooler layer of a lake during summertime thermal stratification.
Macrophytes	Rooted or flooting aquatic plants.
Market Failure	A divergence between the market outcome (without intervention) and the economically efficient solution.
Opportunity cost	The value of goods or services foregone, including environmental goods and services, when a scarce resource is used for one purpose instead of for its next best alternative use.
Oxygen deficit	The difference between observed oxygen concentrations and the amount that would be present at 100 percent saturation at a specific temperature.
Oligotrophic	'Poorly nourished," from the Greek. Describes a lake of low plant productivity and high transparency.
pH	A measure of the concentration of hydrogen ions of a substance, which ranges from very acid (pH = 1) to very alkaline (pH - 14). pH 7 is neutral and most lake waters range between 6 and 9. pH values less than 6 are considered acidic and most life forms can not survive at pH of 4.0 or lower.
Phytoplankton	Microscopic algae and microbes that float freely in open water of lakes and oceans.
Radionuclides	Radioactive subatomic particles.

Secchi depth	A measure of transparency of water obtained by lowering a black and white, or all white, disk (a Secchi disk, 20 cm in diameter) into water until it is no longer visible. Measured in units of meters or feet.
Sediment	Bottom material in a lake that has been deposited after the formation of a lake basin. It originates from remains of aquatic organisms, chemical precipitation of dissolved minerals, and erosion of surrounding lands (see ooze).
Stratification	Layering of water caused by differences in water density. Thermal stratification is typical of most deep lakes during summer. Chemical stratification can also occur.
Secchi depth	A measure of optical water clarity as determined by lowering a weighted Secchi disk into a water body to the point where it is not longer visible.
Suspended solids	Refers to the particulate matter in a sample, including the material that settles readily as well as the material that remains dispersed.
Terrace	An embankment or combination of an embankment and channel built across a slope to control erosion by diverting or storing surface runoff instead of permitting it to flow uninterrupted down the slope.
Trace elements	Those elements that are needed in low concentrations for the growth of an organism.
Urban runoff	Surface runoff from an urban drainage area.
Water quality standards	State-enforced standards describing the required physical and chemical properties of water according to its designated uses.
Watershed	A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.
Zooplankton	Microscopic animals which float freely in lake water, graze on detritus particles, bacteria, and algae, and may be consumed by fish.

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1
Introduction

Less than 3 percent of all water on the planet is fresh; of that, only 0.014 percent is readily available on the surface. Natural lakes of the world, on which hundreds of millions of people depend for their drinking water, contain more than 50 percent of this total. Lake Baikal and the Great Lakes in North America by themselves have more than 40 percent of the water contained in the earth's freshwater lakes.

Lakes have a more complex and fragile ecosystem than rivers. They do not have a "self cleaning" ability, and therefore they readily accumulate pollution. Because of their importance, their beauty, their religious and cultural significance, and their relative vulnerability to degradation, lakes and reservoirs require more concerted attention than is applied generally to river and stream basins. Although pollution of other waterways is also a pressing issue, the unique features and situation of lakes makes it important to deal with them first.

Sustainable use of lakes and reservoirs is being threatened around the globe, both in the North and in the South. Humanity depends on all sizes and kinds of lakes--natural or artificial, ephemeral or permanent--for drinking water, food supply, power production, navigation, ecological services, and economic development. Moreover, lakes are integrators of the many complex chemical, physical, and biological processes occurring throughout entire watersheds. They serve as indicators of adverse environmental change.

Over the last 50 years, the world population has almost tripled. Most of this increase has occurred in developing countries. The use of water during the same period has more than tripled. The exploitation of lands, bodies of water, and forests resulting from development has increased dramatically. This has led to a number of pronounced problems in lakes and reservoirs (hereafter mostly referred to as "lakes"). Changes in the natural landscape from resource extraction, introduction of new and more intensive types of agricultural practices, urbanization, altered water balances, and hydrological regimes have all influenced the state of lakes around the world.

Unfortunately, beneficial uses of lakes are being impaired, expensive investments in infrastructure are being lost, and ecological systems associated with lakes are collapsing. Substantial economic benefits from long-term, sustainable use of lake ecosystems will occur only if degraded lakes are restored and high-quality lakes are protected. If this is not done, permanent, irreversible damage can be expected.

The purpose of this paper is to alert policy leaders and decisionmakers to the importance of lakes and to demonstrate that the lakes and reservoirs of the world are at considerable risk. Continued loss of this resource jeopardizes sustainable economic growth. This paper describes lessons learned from lake degradation as well as from successful experiences in lake and reservoir rehabilitation, highlighting the importance of economic tools and sound financial policies. Processes need to be initiated to strengthen institutions, finances, and policies in order to reverse the continuing degradation and to establish improved approaches for lake and reservoir management.

The paper is neither a scientific treatise or a highly technical paper. Frequently, however, technical terms and concepts are presented to the general audience this paper addresses. Because of lack of consistent data needed to characterize the world-wide status and rate of change in the quality of lakes, the authors have drawn upon specific lake situations that, when considered collectively, characterize the degradation of lakes on a global scale.

The comprehensive approach to water resources management called for in the World Bank's 1993 water resources policy paper (World Bank 1993), is advocated here to protect lake and reservoii ecosystems. Conflicts can be resolved, international lake and reservoir catchments can be more effectively managed, pollution sources can be abated, and over-exploitation can be reduced. This paper calls attention to those issues countries need to address, and describes cases of successful practices for lake and reservoir management.

2
The Complex Interaction of Lake and Reservoir Ecosystems With Their Watersheds

There are many different types of lakes and reservoirs; and they serve many functions and purposes. Some lakes are ephemeral, such as floodplain lakes of large rivers. Others may be located in dry regions and are saline like the Aral Sea in Asia or the Great Salt Lake in America. Small saltwater lakes in coastal zones are essential for production of certain fisheries. Some lakes are recharged almost totally from groundwater inflow, while others, like lake Chad in Africa or small lakes in floodplains or delta areas in Asia, serve to recharge groundwater supplies. Depending on size, depth, climate, and flow regime, lakes differ in vulnerability to pollution.

There are significant differences between tropical and temperate lakes. In temperate lakes, nutrients are circulated during the autumn and winter, and the increase in temperature and illumination are the main triggers for seasonal primary production. Tropical lakes (once thought to show little seasonal primary production variances because of uniformly high temperatures and light throughout the year) also show seasonal variances. These are not as regular as in temperate lakes, and are mostly caused by excessive runoff during the rainy season, when large quantities of nutrients and organic material are carried to lakes, and during windy periods, when mixing is induced frequently to the bottom of shallower lakes. It is wind-induced mixing that causes the seasonal increase in production in Lakes Tanganyika, Malawi, and Victoria (Beadle 1981).

Thornton and Rast (1994) characterize the differences in temperate and tropical lakes by identifying differences in their watersheds. They note that the preponderance of lakes in the tropics are man-made. Watersheds of lakes in southern Africa were 2.5 times larger than those of similar northern lakes. They indicate that unit area loads of sediment, nutrients, and contaminants in southern Africa are similar to northern lakes, but because of the much larger watershed size, overall loading is much higher. This generally leads to bodies of water that are naturally turbid and rich in nutrients.

Lake and reservoir ecosystems contain a multitude of specialized subsystems such as wetlands, floodplains, and groundwater aquifers. Lakes continuously interact with their subsystems to obtain nourishment, inflow water, and a steady supply of organic matter and energy. This depends greatly on the management of their catchments (the geographical area from which the water flowing into a lake or reservoir originates, including the lake surface) and is linked to groundwater and aquifers.

Unfortunately, in the industrialized countries, lake ecosystems have been seldom considered in planning economic development, and a high cost is now being paid in the form of permanent ecosystem damage and expensive remedial action to restore at least some uses of contaminated and degraded systems. Because of the shortage of financial resources, and the need for immediate results, developing countries often do not consider lake--watershed interactions in their planning and projects. Consequently, the development may not be environmentally sustainable, and lake ecosystems on which people depend for their livelihood may be permanently damaged.

3
The Threat to Beneficial Uses of Lakes and Reservoirs

Lakes provide direct and indirect benefits to many segments of society. Lakes are also important ecological features that provide habitat for fish and shellfish, marginal nursery zones for many aquatic and amphibian species, resting places and feeding areas for numerous migratory birds, drinking water for countless species of mammals.

As a source of recreation, lakes support fishing, boating, and swimming. From a commercial point of view, lakes have considerable value in supplying food, supporting tourism, and providing a means of transportation. Lakes serve as flood control features and waste disposal sites. They are important components of hydropower generation, and a source of drinking, industrial, and irrigation water. In addition to these types of strictly economic benefits, people living around lakes demonstrate an affinity toward them. Such benefits are hard to quantify from an economic standpoint.

When valuing the benefits associated with a given lake, one should consider the relationships among the lake ecosystem and socio-economic components as demonstrated in the case of Lake Biwa, Japan (Box 1 and Annex 4). These relationships, which may vary over time and space, are dynamic, and may affect the result of an economic analysis. The relationships can vary according to the size of the lake, its location with respect to travel patterns, its placement in the landscape, its proximity to population centers, and other factors. The value lakes have to humans can and frequently does change in time as shown by Kada (1991) and Kira (1988a) for Lake Biwa. In prehistoric times, the greatest value of Lake Biwa was for production of food. In medieval and feudal times, this value remained important, but Lake Biwa was equally important for transportation. Today, the lake's most important uses are as a source of water, as a tool in flood control, and for both religious and leisure-time activities. All too frequently over-exploitation of a lake basin can increase pollution loading to a lake, which can trigger these changes in the uses and value of the lake.

It is clear that an economic analysis of beneficial uses associated with lakes should be comprehensive, dynamic, and include all potential uses and users since they affect each other. A special feature is the dynamic aspect of lake ecosystem degradation. The capacity of different types of lakes to sustain levels of pollution varies and is limited. In many cases, the damage to lake ecosystems, especially the biological communities, is irreversible. This means that benefits to local populations that depend on lakes are foregone. The poor may lose their source of nutrition, and others may lose their source of employment and may migrate. Furthermore, investments may be wasted. Many lake systems in the world are approaching limits or thresholds where their