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Lakes and Reservoirs

Similarities, Differences and Importance

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Lakes and Reservoirs: Similarities, Differences and Importance
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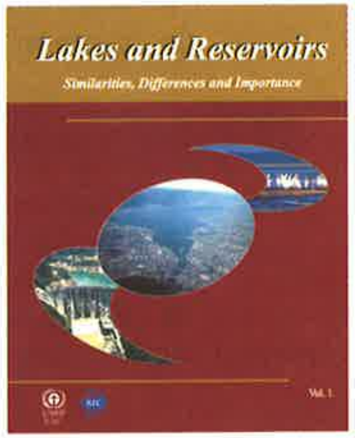

*Cover: Lake Biwa, Japan (middle)
Lake Tsukigase, Japan (left)
Lake Nakuru, Kenya (right)*

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Foreword

We are pleased to present you with this Short Series related to the management of lakes and reservoirs. These water bodies are one of the most important sources of fresh water for agriculture, industry, domestic and drinking purposes while at the same time are the "homes" of a number of different and important species of plants and animals making them sources of fisheries, areas for migratory birds to reproduce or rest, etc..

In general, we are not aware of the efforts required for keeping lakes and reservoirs in good condition so that they can be used for the benefit of society as well as for nature. An enormous amount of money, technical and scientific expertise is required to keep them clean and healthy, which in many occasions is taken for granted.

As the human population grows in the future more demand will be put on lakes and reservoirs. Water levels will become lower as a result of higher consumption from households and industries; an increasing number of people will enjoy them resulting in altering their shores; non-appropriate use of the land, particularly on the hills and mountains, may result in increasing the amount of soil or sediments reaching their basins. Finally, pollution from agricultural lands and domestic sources may produce eutrophication and non-desirable effects such as the presence of toxic algae, reduction of oxygen and generation of foul odour, amongst other negative effects.

With this Short Series UNEP-IETC and ILEC (supported by the Japanese Environment Agency) intends to provide information about lakes and reservoirs considering various aspects related to their nature, importance and management. It is not meant to be a comprehensive technical publication but an accessible and amenable source of information for the citizen by the use of clear language and a minimum of technical jargon to encourage greater understanding.

The intrinsic value of lakes and reservoirs and the efforts to preserve them are larger than we think and as citizens we have to join our efforts with that of the authorities and industries to ensure their preservation and appropriate or sustainable use either for us or for future generations. We sincerely hope that you find the information in this publication interesting and stimulating.

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Why are Lakes and Reservoirs Important?

Introduction

Water is an inescapable necessity for all life on Earth. In pictures taken by astronauts circling the Earth, we see a globe covered mostly by a rich, blue color, signifying the presence of huge quantities of water – approximately 1.4 billion cubic kilometers of it! In fact, the absence of water produces a very dramatic landscape - the most striking feature cited by Astronaut Jay Apt while orbiting the Earth in the space shuttle was a belt of desert extending nearly unbroken from northwest Africa to China.

If we consider human water needs, however, this picture is deceiving. This is because more than 97 percent of the Earth's water is in its oceans, leaving only about 2.5 percent of it on land. Furthermore, about 70 percent of this water is frozen in polar icecaps or glaciers. Most of the rest lies deep underground and beyond easy human reach, and another sizable fraction is saline. This means, therefore, that all human and other life depends on less than one percent of the total quantity of water on this planet.

Even this relatively small fraction, however, is thought to be adequate to meet human freshwater needs, if it were evenly distributed around the world. Unfortunately, nature does not distribute its water resources evenly with regard to either location or time of need. Some areas of the world have a rich supply of fresh water, while others are arid or semi-arid areas with limited supplies. Further, in some areas, nature supplies much of the water at times that do not coincide with human water needs. If there is no mechanism to store this water, much is wasted, or causes serious flooding, with resultant loss of life and property.

Adequate supplies of clean, safe fresh water are fundamental for human survival and well being. That most human civilizations of the world emerged in or near river valleys provides ample evidence of human needs for water. Unfortunately, waterborne diseases and aquatic vectors continue to be the largest single cause of human illness and death around the world.

Fresh water also is a basic requirement for the economic development of nations and regions. Economic development in most arid and semi-arid regions is limited. Humans also find it convenient to dispose of unwanted wastes and byproducts of economic development activities in watercourses.

Fresh Water and the Hydrologic Cycle

Nature supplies fresh water for human needs and the maintenance of the natural environment and ecosystems with a continuous recycling and renewal process of evaporation, precipitation and runoff: the hydrologic cycle *(Fig. 1)*. This cycle provides a continuous supply of fresh water in the form of precipitation and snowfall. After falling onto land, precipitation flows over it in a journey determined by gravity and the Earth's contours, most eventually making its way back to the ocean. Some terminates in inland drainage basins, e.g. the Caspian and Aral Seas.

From the human perspective, the runoff or drainage of water from the land surface is the most important source of fresh water. It also is the primary mechanism by which water on the land surface flows into large downstream rivers and lakes, and eventually into the oceans. On a global scale, water runoff is generally concentrated in the temperate climatic zone and equatorial region, which also contains many developed countries. In contrast, many developing countries are located in the arid, semi-arid, tropical or sub-tropical regions of the world. The volume of runoff from rivers that drain these regions is unevenly distributed. The runoff in the Amazon River, for example, comprises about 80 percent of the average water runoff each year from the entire South American continent. The runoff from the Congo and Zaire Rivers comprise about 30 percent of the annual average water runoff from the continent of Africa. The water runoff from the Ganges-Brahmaputra and Mekong drainage basins comprises a high proportion of the total annual water runoff from Asia.

Fresh water may spend some time in lakes and reservoirs during the course of its journey to the oceans. Referred to by some as "pearls on a river", lakes and reservoirs can have a significant effect on the quantity and the quality of the fresh water that eventually reaches the oceans. It is the intention of this volume to highlight lakes and reservoirs, and illustrate how their similarities and differences can affect human use of this water.

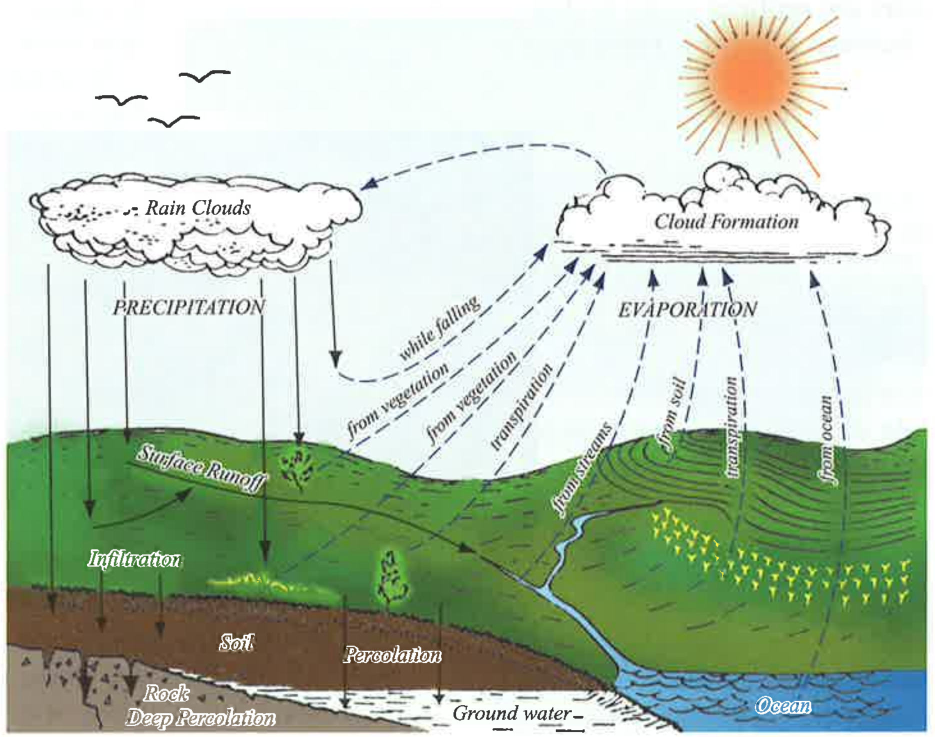

Fig.1 : Hydrologic Cycle

How are Lakes and Reservoirs Formed and Located?

Lakes and reservoirs are dramatic, often visually pleasing, features of the landscape that comprises river drainage basins (also called watersheds or catchments). They range from pond-sized water-bodies to those containing vast quantities of fresh or saline water *(Photos 1 and 2)* and stretching for hundreds of kilometres. For the purposes of this booklet, lakes are water-bodies formed by nature whereas reservoirs are artificial water bodies constructed by humans, either by damming a flowing river or by diverting water from a river to an artificial basin (impoundment). Many characteristics of lakes and reservoirs are a function of the way in which they were formed and the use to which humans put their waters. However, lakes and reservoirs also share a number of common features, involving some that fundamentally control both the quantity and the quality of the water contained in them.

Photo 1: Lake Victoria, in Tanzania, Uganda and Kenya

Photo 2: Lake Eyre, a saline lake in Australia

Photo 3: Glacier Perito Moreno, descending from the Andes mountains and melting in the Lago Argentino, Argentina

Natural Lakes

Simply stated, lakes are naturally formed, usually "bowl-shaped" depressions in the land surface that became filled with water over time. These depressions (also called basins) were typically produced as a result of the catastrophic events of glaciers, volcanic activity, or tectonic movements. The age of most permanent lakes usually is of a geological time frame, but with most not much older than 10,000 years. A few are much older, and some ancient lakes may be millions of years old.

Photo 4: Lake Baikal, the deepest lake in the world, Russia

The most significant past mechanism for the formation of lakes in the temperate areas was the natural process of "glacial scour", in which the slow movement of massive volumes of glacial ice during and after the Ice Age produced depressions in the land surface that subsequently filled with water. The North American Great Lakes (Superior, Michigan, Huron, Erie, Ontario), lakes in the Lake District in the United Kingdom, and the numerous lakes in Scandinavia and Argentina *(Photo 3)* are prominent examples of this type of lake formation.

Photo 5: Lake Nakuru, a rift valley lake rich in colonies of flamingos and white pelicans, Kenya

Another major lake formation process was "tectonic movement", in which slow movements of the Earth's crust produced depressions over time, which subsequently filled with water. Lake basins also formed as a result of volcanic activity, which also produced depressions in the land surface. Most of the Earth's very deep lakes resulted from either volcanic or tectonic activity. Lake Baikal in Russia *(Photo 4)*, the world's deepest lake and one which contains approximately 20 percent of the world's liquid fresh water, and the African Rift Valley lakes *(Photos 1 and 5)* are prominent examples of this type of lake formation.

Photo 6: A beaver's dam in the Truckee River, USA

Other natural processes that produced lake basins include (i) seepage of water down through layers of soluble rock, (ii) erosion of the land surface by wind action, and (iii) plant growth or animal activity (e.g., beavers, *Photo 6*) that resulted in damming of the outlet channels from shallow depressions in the land surface. There are literally millions of small lakes around the world, concentrated largely in the temperate and sub-arctic regions. These regions are also characterized by a relative abundance of fresh water. Many more millions of temporary lakes occur in semi-arid and arid regions.

Man-made Lakes (Reservoirs)

In contrast to natural processes of lake formation, reservoirs are man-made water-bodies, usually formed by constructing a dam across a flowing river. Upon completion of the dam, the river pools behind the dam and fills the artificially created basin. A dam also may sometimes be constructed on the outlet channel of a natural lake as a means of providing better control of the lake's water-level (examples being Lake Victoria, Africa, and Lake Tahoe, USA, *Photo 7*). However, these latter water-bodies typically retain their natural lake characteristics.

Reservoirs are found primarily in areas with relatively few natural lakes, or where the lakes are not suitable for human water needs. They are much younger than lakes, with life spans expressed in terms of historical rather than geological time. Although lakes are used for many of the same purposes as reservoirs, a distinct feature of reservoirs is that they are usually built by humans to address one or more specific water needs. These needs include municipal and drinking water supplies, agricultural irrigation, industrial and cooling water supplies, power generation, flood control, sports or commercial fisheries, recreation, aesthetics and/or navigation.

Photo 7: Lake Tahoe and dam on the Truckee River

The reasons for constructing reservoirs are ancient in origin, and initially focused on the need of humans to protect themselves during periods of drought or floods.

Photo 8: Takayama Dam on the Nabari River, Japan

Accordingly, reservoirs are usually found in areas of water scarcity, or where a controlled water facility was necessary. Small reservoirs were first constructed some 4,000 years ago in China, Egypt and Mesopotamia, primarily to supply drinking water and for irrigation purposes. Simple small dams were constructed by blocking a stream with soil and brush, in much the same manner as beavers dam a stream. Larger reservoirs were constructed by damming a natural depression, or by forming a depression along the river and digging a channel to divert water to it from the river. Early irrigation practices were linked largely to land adjacent to streams. It required the construction of larger dams, which allowed humans to impound larger volumes of water, before irrigation of agricultural land located distant from the water source could occur. Later reservoirs also were used as a source of power, first for moving waterwheels, and subsequently to produce hydroelectric power.

Like lakes, reservoirs range in size from pond-like to very large water-bodies. The variations in type and shape, however, are much greater than for lakes. The term 'reservoir' includes several types of constructed water-bodies and/or water storage facilities; namely, (1) valley reservoirs - created by constructing a barrier (dam) perpendicular to a flowing river *(Photo 8)*, and (2) off-river storage reservoirs - created by constructing an enclosure parallel to a river, and subsequently supplying it with water either by gravity or by pumping from the river. The latter reservoirs are sometimes also called embankment or bounded reservoirs, and have controlled inflows and outflows to and from one or more rivers. In addition to single reservoirs, reservoir systems also exist, and include (i) cascade reservoirs - consisting of a series of reservoirs constructed along a single river, and (ii) interbasin transfer schemes - designed to move water through a series of reservoirs, tunnels and/or canals from one drainage basin to another *(Fig. 2)*.

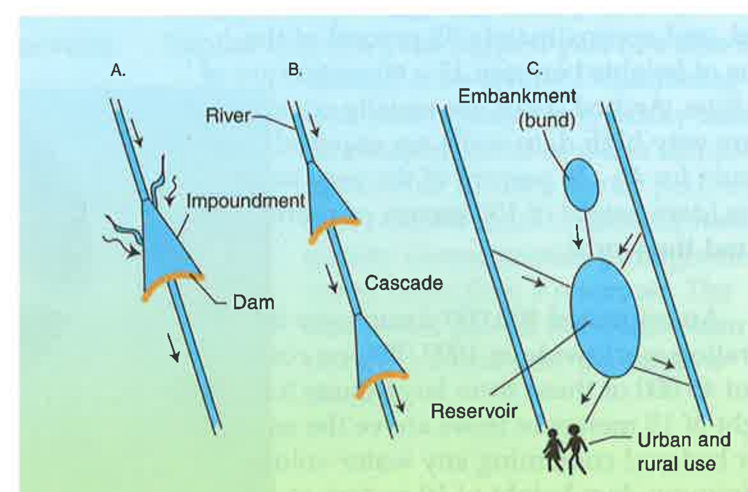

Fig. 2: Different types of reservoir systems

Because they have both river-like and lake-like characteristics, reservoirs constitute an intermediate type of water-body between rivers and natural lakes *(Fig. 3)*. Their flushing rate and the degree of river influence ultimately determines the specific characteristics and potential uses of reservoirs.

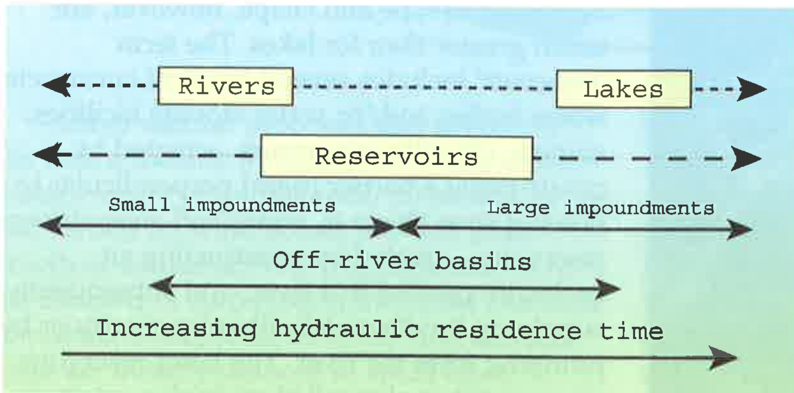

Fig. 3: The intermediate position of reservoirs between rivers and natural lakes

Several types of dams are constructed to make reservoirs, including earth-fill, gravity, arch and buttress. Very small dams (dam height of three - six metres above the natural river bed) could be used to strore river water for drinking purposes *(Photo 9)* or to divert the water flow of smaller rivers for various purposes, including the operation of mill water wheels. The most common type of dam is earth-filled, and approximately 85 percent of the dams of heights between 15 - 60 meters are of this type. Arched dams are usually constructed where very high dam walls are required, and account for 40 - 50 percent of the very large dams (dam height of 150 meters or more) around the world.

An estimated 800,000 dams were in operation worldwide in 1997. By one count, about 45,000 of these were large dams (i.e., dam height of 15 meters or more above the natural river bed and containing any water volume, or a minimum dam height of 10 meters and a volume of at least one million cubic metres). Approximately 1,700 more large dams are currently under construction, particularly in developing countries. Most reservoirs are concentrated in the temperate and sub-tropical zones of the northern and southern hemisphere. Nearly all major river systems in the world have reservoirs in their drainage basins, and a number of river systems (e.g., Columbia, Dnieper, Volga, Angara, Parana, Missouri) also have cascades of reservoirs within their basins. It has been estimated that approximately 25 percent of all water previously flowing to the oceans is now impounded in reservoirs. In fact, reservoirs exist on all continents and in all countries (except Antarctica), although their distribution within specific countries and regions is irregular. Construction of new reservoirs has essentially ceased in North America and Europe. In contrast, reservoir construction is continuing in developing countries, with nearly all new reservoirs scheduled to enter operation in the 21st Century located in Asia, Africa and Latin America.

Photo 9: Turasha River Dam for water supply, Kenya

How are Lakes and Reservoirs the Same and How are They Different?

Standing on the shoreline, a large lake or reservoir look much the same, and both often contain the word "lake" in their name. Furthermore, the same principles of biology, chemistry and physics are applicable to both types of water-body. Indeed, it may be difficult to discern any obvious differences between a lake and reservoir but differences there are, as well as similarities. It is the intention of this chapter to examine some of these as well as the implications for attempting to manage these two types of water-bodies effectively.

The science that deals with lakes and reservoirs is known as limnology, and much of our current limnological knowledge (including that used to manage lakes and reservoirs) was derived from studies of lakes over many decades. Although we now have a reasonable understanding of limnological processes in lakes, we now are only just beginning to develop a similar understanding for reservoirs.

In fact, reservoir studies initially focused on sediment loading from drainage basins. The rationale for this was that the rate at which a reservoir filled with sediment is a major determinant of useful operational life. Comparatively little attention was given to the environmental and socioeconomic issues associated with reservoir construction.

Shape and Morphometry

The shape and form of lakes and reservoirs is determined largely by how they were formed. This also affects some of their fundamental characteristics. Because lakes are naturally formed, bowl-shaped depressions typically located in the central part of a drainage basin, they usually also have a more rounded shape than reservoirs *(Photo 10)*. Similar to a bowl, the deepest part of a lake is usually at its center. Determining lake water quality is typically based on measurements of water samples taken from its deep center part, and a lake exhibits more consistent water quality characteristics throughout its water basin than a reservoir. The shallowest part of the water basin is usually located near the outflow channel.

Photo 10: The rounded shoreline of a natural lake, Lake Attersee, Austria

In contrast, a reservoir often has a shape that is fundamentally different from lakes; its deepest part is near the dam. Moreover, because a river often has a number of streams or tributaries draining into it, when the river is dammed, the impounded water tends to back up into the tributaries. As a result, many reservoirs have a characteristic dendritic shape, with the "arms" radiating outward from the main body of the reservoir *(Photo 11)*. In contrast, a reservoir formed by damming a river with high banks will tend to be long and narrow. Depending on how they were constructed, off-river storage reservoirs can have many shapes.

The dendritic shape or branching form of many reservoirs provides a much longer shoreline than in lakes of similar volume. Reservoirs also usually have longer drainage basins than lakes. Because of their larger drainage basins, and their multiple tributary inputs, the inflow of water into reservoirs is more directly tied to precipitation events in the drainage basin than it is in lakes. Further, because the deepest parts of most reservoirs are just upstream of the dam, the possibilities for draining the reservoir are facilitated. A lake typically cannot be emptied; its deepest part is usually in its center.

Damming a river also inundates land previously above water. This sometimes forces the relocation of inhabitants and wildlife living around the reservoir. The presence of a dam downstream also allows a greater degree of control of water-levels and volumes for reservoirs than for lakes. Constructing water discharge structures at different levels in the dam also allows withdrawal or discharge of water from selected depths in a reservoir. "Selective withdrawal" has major implications for the water-mixing characteristics and increases flushing possibilities for reservoirs.

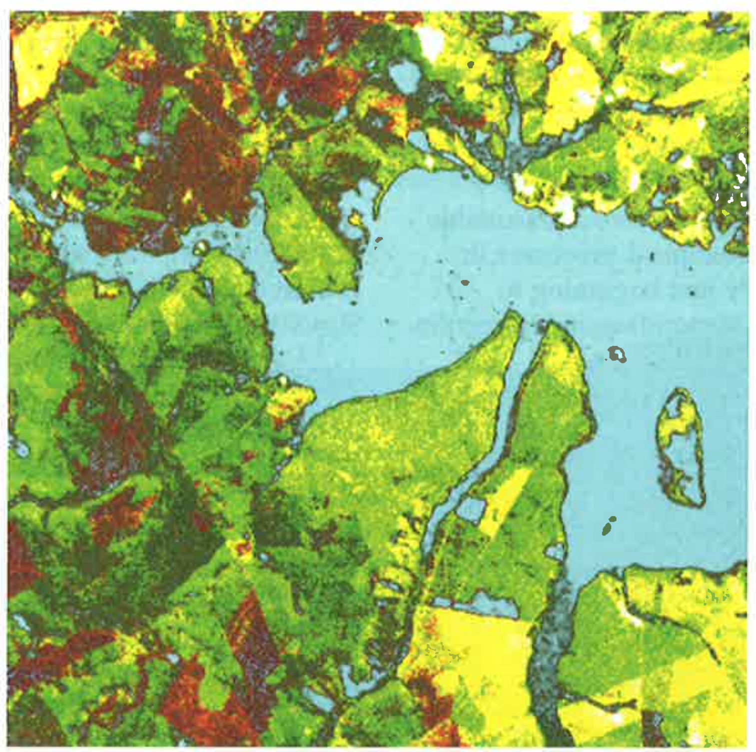

Photo 11: Characteristic dendritic shape of a large reservoir, Barra Bonita Reservoir, Brazil

Water Quality

The physical character and water quality of rivers draining into lakes and reservoirs are governed in part by the velocity and the volume of river water. The characteristics of the river water typically undergo significant changes as the water enters the lake or reservoir, primarily because its velocity reduces: sediment and other material carried in the faster-flowing water settle out in the basin, undergoing sedimentation. The structure of the biological communities also changes from organisms suited to living in flowing waters to those that thrive in standing or pooled waters. Greater opportunities for the growth of algae (phytoplankton) and the development of eutrophication are present too.

Reservoirs typically receive larger inputs of water, as well as soil and other materials carried in rivers than lakes. As a result, reservoirs usually receive larger pollutant loads than lakes. However, because of greater water inflows flushing rates are more rapid than in lakes. Thus, although reservoirs may receive greater pollutant loads than lakes, they have the potential to flush the pollutants more rapidly than do lakes (as one can more rapidly flush water from a bathtub by increasing the water flow and/or the rate at which the water is drained from the tub). Reservoirs may therefore exhibit fewer or less severe negative water quality or biological impacts than lakes for the same pollutant load.

The water quality of lakes and reservoirs is defined by variables measured within the water basin *(Photo 12)*. Although there are many variables of limnological significance, water quality is typically characterized on the basis of such variables as water clarity or transparency (greater water clarity indicates better water quality), concentration of nutrients (lower concentrations indicate better water quality), quantity of algae (lower levels indicate better water quality), oxygen concentration (higher concentrations are preferred for fisheries), concentration of dissolved minerals (lower values indicate better water quality), and acidity (a neutral pH of 7 is preferred).

Photo 12: Measuring water quality in New Jersey, USA

Many waste chemical compounds from industry, some with toxic or deleterious effects on humans and/or water-dependent products, are discharged into lakes and reservoirs. These can kill aquatic organisms and damage irrigated crops. Because of inadequate water purification the quantity of bacteria, viruses and other organisms in discharged waters are a primary cause of waterborne disease. Although dangerous to human health worldwide, such problems are particularly severe in developing countries.

Major differences between deep and shallow water-bodies, whether lakes or reservoirs, occur. Deep lakes, particularly in non-tropical regions, usually have better water quality in lower layers. Shallow lakes *(Photo 13)* do not exhibit this depth differentiation in quality and their more shallow, shoreline areas have relatively poorer water quality because they are where pollutant inputs are discharged and areas with a greater potential for disturbance of bottom muds, etc. Thus, the water quality of a natural lake usually improves as one moves from the shoreline to the deeper central part. In contrast, the deepest end of a reservoir is immediately upstream of the dam so that water quality usually improves along the length of a reservoir, from the shallow inflow end to the deeper, "lake-like" end near the dam.

Reservoirs, particularly the deeper ones, are also distinguished from lakes by the presence of a longitudinal gradient in physical,

Photo 13: Areas of siltation, Southern Indian Lake, Canada

chemical and biological water quality characteristics from the upstream river end to the downstream dam end. Thus, reservoirs have been characterized as comprizing three major zones: an upstream riverine zone, a downstream lake-like zone at the dam end, and a transitional zone separating these two zones *(Fig. 4)*. The relative size and volume of the three zones can vary greatly in a given reservoir.

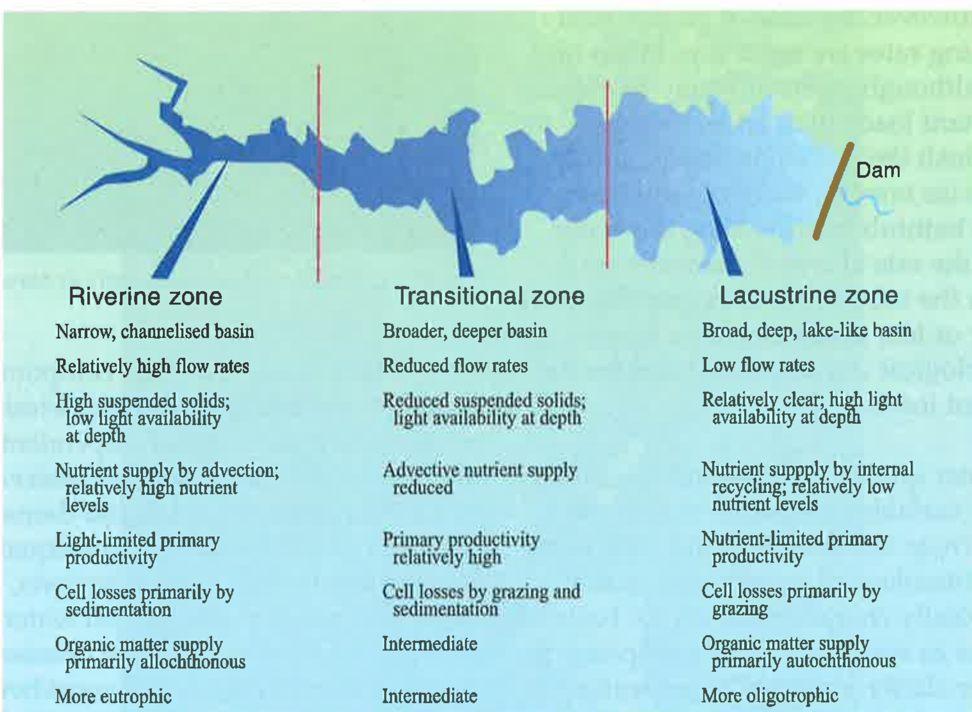

Fig. 4: Longitudinal zonation of water quality and other variables in reservoirs

Downstream Characteristics

Constructing a dam can produce dramatic changes in the downstream river channel below the dam that are quite unlike downstream changes from lakes. Because reservoirs act as sediment and nutrient traps, the water at the dam end of a reservoir is typically of higher quality than water entering the reservoir. This

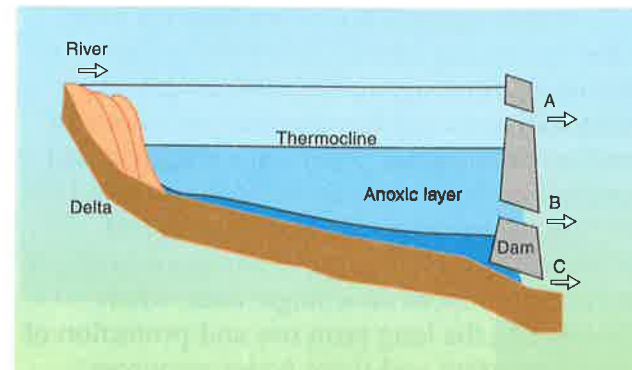

Fig. 5: Different levels of possible water discharge from a dam

Photo 14: Lower water discharge at Amagase Dam, Japan

higher-quality water subsequently flows into the downstream river channel below the dam. This phenomenon is sometimes a problem in that the smaller the quantity of sediments and other materials transported in the discharged water, the greater the quantity that can be picked up and transported as it moves downstream. Because it contains less sediment the discharged water can scour and erode the streambed and banks as it picks up new sediment as it continues downstream. This scouring effect can have significant negative impacts on the flora, fauna and biological community structure in the downstream river channel. The removal of sediments from a river by reservoirs also has important biological effects, particularly on floodplains.

Many reservoirs, especially those used for drinking supplies, have water release or discharge structures located at different vertical levels in their dams *(Fig. 5)*. This allows for the withdrawal or discharge of water from different layers within the reservoir, so called "selective withdrawal" *(Photo 14)*. Depending on the quality of the water discharged, selective withdrawal can significantly affect water quality within the reservoir itself, as well as the chemical composition and temperature of the downstream river. The ability to regulate or schedule water and silt discharges *(Photos 15, 16 and 26)* also can fundamentally change downstream hydrological regimes, affecting both flora and fauna.

Constructing a reservoir to protect downstream areas from floods often has significant social and economic implications, including the potential for stimulating urban and agricultural development adjacent to, and below, the reservoir. This can have both positive and negative impacts, depending on the nature and size of development.

Photo 15: Seta River Weir, Japan

Photo 16: Operation room of the Seta River Weir meant to regulate water discharge, Japan

Management of Lakes and Reservoirs

The Nature of Lake and Reservoir Water Problems

Because the drainage basin is simultaneously (i) the source of water, (ii) the place where it is used, and (iii) where human activities impact both water quantity and quality, the drainage basin is the logical management unit for lakes and reservoirs. Activities that generate pollutants (e.g., urbanization, industrialization, agricultural production) are similar in both lake and reservoir drainage basins, whether from point or nonpoint pollution sources. Point sources are 'pipeline' discharges of pollutants to receiving waters, e.g. domestic sewage discharges or industrial waste effluents from factories or plants. They are relatively easy to identify and isolate. In contrast, nonpoint pollution results from storm runoff or snowmelt, which transports polluting materials diffusely and over land in urban and agricultural areas to rivers, lakes and reservoirs. Thus, non-point source pollution is closely tied to precipitation and runoff events, and less predictable and more variable in nature. Because of their diffuse nature, nonpoint pollutant sources are also more difficult to identify and deal with.

Lakes and reservoirs are used for many, often competing human needs *(Photo 17)*, including drinking, agricultural irrigation, industrial and cooling water supply, sports or commercial fisheries *(Photo 18)*, recreation and navigation. Reservoirs are often constructed for the specific purposes of flood control and power generation too *(Photo 19)*. Accordingly, it is difficult to focus on a single issue when considering the long term use and protection of these important and finite water resources.

Of particular importance in addressing lake and reservoir problems is the need to consider an "ecosystem approach". Here, rather than adopting the sectoral approach that focuses on a single water use, the ecosystem approach considers both human water needs within the larger context of the drainage basin and environmental water needs or ecological requirements. This approach, therefore, is a prudent means of balancing the water needs for economic development and environmental protection.

Photo 17: Urban development in the southern basin of Lake Biwa, Japan

Photo 18: Fishing practices in Lake Songkhla, Thailand

Photo 19: Electricity production, Reservoir Lago de Salto Grande, on the border of Uruguay and Argentina

Virtually all lake and reservoir water problems are related either to issues of (1) quantity - there is too little or too much water, or (2) quality - the water is too degraded (polluted) for drinking water supply, agricultural irrigation and/or industrial or other purposes. The problem of too little water results either from limited precipitation or excessive water usage. In contrast, the problem of too much water is typically manifested as floods. Solutions to these problems, therefore, usually involve developing larger water supplies or reducing current water uses, respectively.

Water quality problems typically involve water pollution issues. Major water pollutants include a variety of organic and inorganic chemicals such as heavy metals and industrial compounds. They can affect human health and/or interfere with industrial or agricultural water use. If the level of a pollutant in the water supply exceeds an acceptable level for a given water use (e.g., domestic or industrial water supply), the water is considered unsafe or too degraded for that use. Solutions to lake and reservoir pollution problems, therefore, usually focus on reduction of pollution at the source and/or treatment of the polluted water prior to use.

Considerations Unique to Reservoirs

Many processes in reservoirs and downstream rivers are complex, long term and "non-traditional" from the perspective of current understanding of lake and river limnology *(Table 1)*. Some non-traditional processes are because reservoirs represent an intermediate aquatic system, one between a flowing river and a lake *(Fig. 3)*, and our limnological understanding of these processes is in its infancy. Nevertheless, each is of significant ecological importance for reservoir management and downstream protection.

Because reservoirs are man-made water-bodies, they are more amenable to artificial operation and regulation than lakes. As previously noted, operational possibilities unique to reservoirs include the ability to (1) discharge known volumes of water at predetermined times, and (2) selective discharge of water from different water layers within the reservoir.

The presence of a reservoir in a drainage basin where no such water-body previously existed significantly impacts on the watercourse, its flora and fauna, and the human inhabitants in the drainage basin. These potential impacts should be identified and thoroughly examined prior to reservoir construction, in order to comprehensively assess the total value of the reservoir project. Procedures to identify and properly evaluate potential environmental, social and economic consequences of reservoir construction involve so-called 'Environmental Impact Assessment' (EIA). Such an assessment is now obligatory by law in many countries for all new dam construction.

Photo 20: Lower section of the Narmada River, India

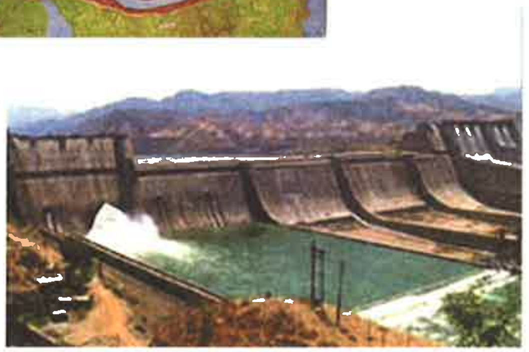

Photo 21: Sardar Sarovar Dam under construction, River Narmada, India

Reservoir Development in the Future

Reservoirs represent an important component of the social and economic structure of both developed and developing countries. Reservoir construction is largely completed in North America and Europe, but continues in the developing world, and most new reservoirs in the future will be located in Asia, Africa and Latin America. In some cases it has been found that the environmental disbenefits of dams outweighs their economic benefit. Thus, in the United States, the federal government has refused to renew the operating licenses of some reservoirs in several locations throughout the USA.

Particular interest is now being directed to ongoing or planned construction of large dams. In some cases, these have incited serious public and international concern, as in the case of the Sardar Sarovar Dam in India *(Photos 20 and 21)*. On the one hand, proponents of large dams say that they bolster local economies, improve energy supply and flood control, and help manage the world's water resources more effectively. The opponents of large dams say that dams cause significant damage to the environment and the local culture, and produce little overall economic gain.

These conflicting points of view require

Table 1. Comparison of the general characteristics of lakes and reservoirs on a global scale

Lakes	Reservoirs
Especially abundant in glaciated areas; orogenic areas are characterized by deep, ancient lakes; riverine and coastal plains are characterized by shallow lakes and lagoons	Located worldwide in most landscapes, including tropical forests, tundra and arid plains; often abundant in areas with a scarcity of natural lakes
Generally circular water basin	Elongated and dendritic water basin
Drainage: surface area ratio usually <10:1	Drainage: surface area ratio usually >10:1
Stable shoreline (except for shallow, lakes in semi-arid zones)	Shoreline can change because of ability to artificially regulate water level
Water level fluctuation generally small (except for shallow lakes in semi-arid zones)	Water level fluctuation can be great
Long water flushing time in deeper lakes	Water flushing time often short for their depth
Rate of sediment deposition in water basin is usually slow under natural conditions	Rate of sediment deposition often rapid
Variable nutrient loading	Usually large nutrient loading
Slow ecosystem succession	Ecosystem succession often rapid
Stable flora and fauna (often includes endemic species under undisturbed conditions)	Variable flora and fauna
Water outlet is at surface	Water outlet is variable, but often at some depth in water column
Water inflow typically from multiple, small tributaries	Water inflow typically from one or more large rivers

Photo 22: Battle Lake, Canada

Photo 23: Shorenji Reservoir, Japan

Photo 24: Silting in the Sanmenxia Dam, Yellow River, China

major attention be given to balancing the beneficial and adverse environmental and socio-economic impacts to be expected with the construction of large dams *(Table 2)*. This attention must begin early in the planning stage to insure that it is properly considered by all relevant parties and interests prior to initiation of construction activities. The Sanmenxia Dam on the Yellow River, China *(Photo 24)*, provides an example of problems that were not sufficiently considered prior to dam construction. Finished in 1960, the goals of the reservoir construction were to prevent floods, provide water for irrigation, and produce hydroelectric power. However, significant silt loads in the Yellow River were not adequately considered in the planning sstage. The reservoir water basin was largely filled with silt only four years after construction, and the reservoir was subsequently taken out of operation. Another example is the construction of the Aswan High Dam *(Photo 25)* which impounded the Nile River. The dam has now been in operation for about 30 years, and based on a comprehensive assessment report of 1989, both positive and negative impacts have resulted from this reservoir project. The economic positive impacts include (i) an improvement of summer crop rotations and guaranteed availability of irrigation water for agricultural production, (ii) expanded rice cultivation (iii), conversion of about one million acres from seasonal to perennial irrigation, (iv) an expansion of about 1.2 million acres of new land due to increased water availability, (v) protection from high floods and droughts, (vi) generation of significant quantities of hydroelectric power, (vii) improved navigation possibilities, and (viii) increased tourism. The negative environmental and social impacts include (i) declining water-levels at Nile River barrages

Photo 25: The Aswan High Dam, border of Egypt and Sudan

Photo 26: Webedacht Dam, South Africa, during sediment flushing

Table 2. Positive and negative effects of large reservoir construction*

Positive Benefits	Negative Effects
· Production of energy (hydropower);	· Displacement of local populations following inundation of reservoir water basin;
· Increased low-energy water quality improvement;	· Excessive human immigration into reservoir region, with associated social, economic and health problems;
· Retention of water resources in the drainage basin;	· Deterioration of conditions for original population;
· Creation of drinking water and water supply resources;	· Increased health problems from increasing spread of waterborne disease and vectors;
· Creation of representative biological diversity reserves;	· Loss of edible native river fish species;
· Increased welfare for local population;	· Loss of agricultural and timber lands;
· Enhanced recreational possibilities *(Photo 27)*;	· Loss of wetlands and land/water ecotones;
· Increased protection of downstream river from flooding events;	· Loss of natural floodplains and wildlife habitats;
· Increased fishery possibilities;	· Loss of biodiversity, and displaced wildlife populations;
· Storage of water for use during low-flow periods;	· Need for compensation for loss of agricultural lands, fishery grounds and housing
· Enhancement of navigation possibilities;	· Need for compensation for lost fishing, recreational and subsistence activities;
· Increased potential for sustained agricultural irrigation	· Degradation of local water quality *(Photo 31)*;
	· Decreased river flow rates below reservoir, and increased flow variability;
	· Decreased downstream temperatures, transport of silt and nutrients;
	· Decreased concentrations of dissolved oxygen and increased concentrations of hydrogen sulfide and carbon dioxide in reservoir bottom water layer and dam discharges;
	· Barrier to upstream fish migration;
	· Loss of valuable historic or cultural resources (e.g., burial grounds, relic sites, temples);
	· Decreased aesthetic values
	· Increased seismic activity

**Not all impacts occur in individual reservoir cases.*

Photo 27: Recreational activities, Lake Biwa, Japan

downstream of the dam, (ii) rising water-levels upstream of the Delta Barrage, (iii) increased riverbank erosion and river meandering, (iv) production of river channel scour holes downstream of existing river barrages, (v) decreased water quality due to increased industrial and agricultural discharges, (vi) increased reservoir siltation, (vii) increased reservoir eutrophication, (viii) increased water evaporation, (ix) increased coastal erosion at the mouth of the Nile River, (x) decreased human health due to increased incidence of schistosomiasis and spread of water-related vectors, and (xi) inundation of historical monuments.

The overall conclusion of the assessment report was that the Aswan High Dam has had an overall positive effect, although it contributed to some significant environmental problems as well. The results of further detailed analyses like this one will undoubtedly provide

Photo 28: Solid waste pollution in Amagase Dam, Japan

Photos 29 and 30: Public participation for the removal of waste in Lake Biwa and Nagasawa River, Japan

information and guidance to those considering the construction of large dam projects in future years, particularly in developing countries.

Protection of Lakes and Reservoirs

As noted, lakes and reservoirs are complex aquatic ecosystems, as well as important sources of water for human use and ecosystem maintenance. Many people assume that the management and protection of lakes and reservoirs is primarily a function of the local, state or federal government. It is certainly true that most major water supply development, flood and water pollution control efforts are usually carried out or directed by governmental bodies in one way or another, but much can also be done at the level of the individual. Collectively, individual citizen input can contribute significantly to protecting and conserving lakes and reservoirs and their living aquatic resources. To effectively protect a lake or reservoir, for example, it is desirable to gather as much information as possible about it. This can help to define problems and consider solutions. Because of public and political pressures, however, decisions about environmental protection must sometimes be made in a relatively short time, regardless of the state of knowledge on the problem. Ironically, in some cases the problem is not too little information, but rather how to make sense of an array of persuasive fact and/or opinion on both sides of an issue. In such cases, solutions are sometimes sought with little real knowledge of facts and even less knowledge about consequences.

The public can play a major role in such situations and it can be very beneficial to seek the public's view, in the form of public hearings or other relevant fora. An example is the creation of a citizen's advisory committee, including inhabitants that live in the lake or reservoir drainage basin. These committees can provide valuable insights and information about past conditions of a lake or reservoir, particularly in the absence of written records. In such cases, narrative descriptions of prior conditions, remembered by 'elders' can be used as an initial reference point for identifying current problems and possible solutions. Some basin inhabitants also may have specific expertise they can bring to bear, e.g. engineers, limnologists and chemists. The participation of non-technical individuals is equally important in protecting lakes and reservoirs, e.g. farmers, urban planners, lawyers, economists and communication specialists. Knowledge gained in this manner can be disseminated among the general basin population, and so prepare people for more informed future judgments and actions. The nature of such materials can vary with the intended audience, and its dispersal can include the press, television and radio, and 'popular' publications. Such efforts facilitate the development of a proprietary interest on the part of the drainage basin inhabitants regarding the nature of lake or reservoir problems, and make them more sympathetic to bearing the costs of solutions.

The views of individuals and groups can inform decision-makers of the public will.

Drainage basin-scale environmental education and training activities are also important activities in this respect. Citizens can form partnerships with relevant authorities to identify lake and reservoir problems and map-out solutions. Citizens can be especially effective in advocacy efforts, and in lobbying for specific issues directed to lake and reservoir protection. Maximum use should be made of the media, particularly in helping identify and highlight lake and reservoir problems and the consequences of ignoring them. Indeed, the possibilities for public involvement in protecting and conserving lakes and reservoirs are limited only by the imagination and ambition of facilitators and participants *(Photos 28, 29 and 30)*.

Many simple protection and conservation actions within a lake or reservoir drainage basin can be directly undertaken by individuals; reducing or eliminating polluting wastes at the source, for example, can be done within households, including using smaller amounts and/or substitutes for polluting materials. Considerable water savings can be made by reduced and/or more efficient water usage in households. Indeed, virtually any activity on the level of the individual household that reduces the usage of water and the generation of water polluting wastes will benefit lakes and reservoirs in the same manner as their application at the drainage basin level.

Lake and reservoir protection measures often may consider 'high tech' solutions to pollution problems; such options as constructing treatment plants to treat polluted water prior to its discharge to lakes and reservoirs, as well as recycling or reusing wastewaters. However, 'low-tech' can often be effectively applied by individuals. Such options typically include changing ingrained behaviour patterns, ranging from convincing farmers to change their agricultural fertilizer application practices to educating people about the dangers of spreading their wastes indiscriminately on the land surface where they can be washed away in storm runoff. As another example, a farmer far from a lake or reservoir may not appreciate his/her role in causing problems. Accordingly, 'low-tech' approaches typically must include some effort to increase public awareness and education, to provide information to individuals on how they can contribute to solving lake and reservoir problems.

Even after efforts to resolve a lake or reservoir water quantity or quality problem, one's efforts may not necessarily be completed: any conclusion that further actions are not required can be false. In fact, post-project monitoring always should be undertaken to evaluate the effectiveness of lake and reservoir protection measures or programs.

Monitoring efforts also provide a basis for determining the extent of improvements achieved, and for determining whether or not the lake or reservoir protection goals are being achieved, as well as for making needed corrections to an ongoing program. The longer a lake or reservoir takes to respond to protection measures, the longer the period of time needed for post-program monitoring efforts.

Photo 31: Toxic algal growth resulting from organic pollution, Sulejow Reservoir, Poland

GLOSSARY:

Advection: flow of air or water within the atmosphere or water-body
Allochthonous: transported from elsewhere
Autochthonous: from the same place
Catchment: the area from which rainfall flows into a river, lake or reservoir
Dendritic: "tree branch-like" shape
Drainage Basin: region surrounding a lake or reservoir from which water is drained
Ecology: the study of organisms, their non-living environment, and the interaction between both
Eutrophication: process whereby lakes and reservoirs become enriched with nutrients (phosphorous and nitrogen mainly)
Fauna: animals
Flora: plants
Impoundment: a confined body of water
Lacustrine: of or pertaining to a lake or lakes
Limnology: the study of inland waters
Nutrients: chemical compounds needed by animals and plants to support life
Oligotrophic: low or lacking nutrients
Plankton: free-floating microscopic plants and animals
Runoff: carried by water originated from rain mainly
Sedimentation: process in which suspended particles settle to bottom
Water quality: a description of how good (adequate) a water is for a particular purpose
Watershed: either the dividing line between two water catchments or the catchment itself

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