

Chapter 8: Informing the Process: The Role of Science

Information Needs for Lake Basin Management

Information is necessary for good decision making, but is costly and never perfect. This is the dilemma facing all decision makers—how to balance the need for further study with the need for action. In the absence of any good information, a decision maker could simply flip a coin and hope for the best: this is obviously not desirable. Nor is it desirable for the decision-making process to be paralyzed because 100% certainty has not been obtained about the current state of a lake basin or about the effects a range of policies may have on it. This chapter draws lessons from the 28 LBMI cases on the search for an appropriate balance. It also incorporates newly commissioned work on some of the cutting-edge fields of lake basin management such as remote sensing and geographical information systems (GIS).

Information comes in a variety of forms. Many readers will immediately think of “scientific information”, such as the values of measured parameters like dissolved oxygen, nutrient concentrations and biomass counts that come from scientific studies and monitoring programs. The use of this “hard” information is indeed important and forms the bulk of this chapter. When devising and implementing policies, however, it is also very important to know socio-economic information about the watershed; to know about cultural values and people’s view of the resource; to know about the institutional and policy frameworks that exist—to know what is possible and what is not (see Box 8.4).

Another valuable source of lake information resides in the memories and experiences of indigenous people living along a lakeshore or in lake basin communities. Often this local knowledge can augment scientific information. In the absence of long-term monitoring programs, it may be the only source of information about a given lake. Thus, in the absence of scientific data, the Ugandan government has been able to use local knowledge to identify and protect important fish breeding areas on the eastern shore of Lake Albert on the border between Uganda and The Democratic Republic of the Congo.

No matter what form information takes, the long retention time, complex dynamics, and integrating nature of lakes, mean that good information is particularly valuable in the decision-making process because the cost of a mistake (or missed opportunity) can be very high. Reflecting

the experience at lakes around the world, this chapter first discusses the uses (and “non-uses”) of science, then covers monitoring as a special topic before considering lessons learned on how information is shared and how information gathering is carried out.

Use of Scientific Information

There are many examples of how the use of science and other types of information has led to better decision-making. In general, science is used in three main ways: (1) to show the limits of resource, (2) to enlighten hard-to-see connections and (3) to provide novel/innovative solutions.

Showing limits to a resource

Fishing is one of the main resource uses in many of the lakes in this survey; overfishing is one of the main problems. Overfishing threatens lake ecosystems and livelihoods built upon them, especially in developing countries. One of the key contributions of scientific studies has been information leading to moratoria on fishing (e.g. Lakes Baringo and Naivasha) or restrictions on allowable technologies (e.g. Lakes George, Ohrid, and Victoria). As a result of the policies based on this information, these fisheries have either recovered, or are in better shape than they would have been without the policy change.

Another common problem facing many lakes is eutrophication, caused by excessive nutrient load (usually phosphorus; occasionally nitrogen) generated from human activities in a lake’s drainage basin (and sometimes beyond). A lake can absorb a certain quantity of nutrient load without showing dramatic changes. However, there also is often a point at which the loading becomes excessive, leading to a major (usually undesirable) shift or imbalance in the lake ecosystem. The extent of the nutrient load, along with information on how much is “tolerable” is a key contribution of science. The LBMI briefs on Lakes Champlain, Constance and the North American Great Lakes show how far science can actually go in aiding the decision-making process. For example, based on a comprehensive modeling exercise, the United States and Canada acted jointly to reduce the phosphorus load to the Great Lakes, mainly by enhancing phosphorus removal at wastewater treatment plants and by

banning P-containing detergents in the drainage basin. It is interesting to note that, even though this policy was successful in controlling much of the point-source load to the lakes, recent study has shown that nonpoint sources also must be controlled to fully meet the targets. The Lake Baikal case also demonstrates how scientific study can reveal that nonpoint sources can be a major threat to a lake.

Enlightening hard to see connections

Lakes are complex. It is not enough for humans to rely on gut feelings arising from everyday experience because human judgment is not necessarily suited to understanding complex ecosystems. A key role of science, therefore, is to shed light on hard-to-see, indirect connections that are common in lake management. Some examples include the following:

- For Lake Naivasha, there was a controversy about the causes of the declining water level. A simple model was developed, making use of long-term monitoring data, to show that abstractions for horticulture and not other causes, such as climate variability, were almost certainly responsible for the decline in lake level. As a result, there was widespread acceptance of this cause and an understanding that different interest groups needed to work together to use the lake's resources equitably. (See Box 8.1 for a fuller discussion.)
- For Laguna de Bay, scientific investigations showed the negative effects of a hydraulic control structure (designed to stop salt water intrusion from the ocean) on the lake fisheries. Eventually, it was decided to halt operation of the structure, allowing natural salt water intrusion occur again, resulting in a decrease in turbidity and improved conditions for fisheries.
- For Lake Biwa, it was shown that decreasing snowfall amounts over the last few decades along with a weakening of the spring overturn (both possibly related to climate change) led to a decrease in the transfer of large amounts of dissolved oxygen (from snowmelt and from the atmosphere) to the hypolimnion every spring, resulting in possibly anoxic conditions at certain times, with the potential for large-scale phosphorus release from sediments and a rapid worsening of the eutrophic conditions.
- For the North American Great Lakes, research has shown the connection between fossil fuel burning at distant power plants and mercury deposition to the lakes. These sources are mostly outside of the watershed but part of the "airshed" and, therefore not one of the first pollutant sources normally considered by decision makers.
- For Lake Victoria, recent studies suggest the role of atmospheric deposition of phosphorus to the lake has

been greatly underestimated. If confirmed, this unexpected pathway could have major implications for managing the lake.

Providing Innovative/Novel Approaches (to solve conflicts)

Finally, science can be used to develop innovative and novel approaches to address a range of lake problems. Some of good examples include:

- For the Chilika Lagoon, modeling studies showed how dredging a channel between the lake and the ocean could improve salinity conditions and fishery production in the lake. The channel was dredged, leading to a dramatic recovery in the fishery and prawning catches. Apart from restoring livelihoods fisherfolk, this action also alleviating a major source of conflict among the local communities.
- At Lake Kariba, ecological studies showed how introduction of a fish (*Limnothrissa miodon*) into an ecological niche opened up by the formation of this reservoir provided a commercially valuable fishery.
- For Lake Chad, test releases from the Tiga and Challawa dams showed that such releases could perfectly simulate wet season conditions. This demonstrated that the dam outlets and the Hadejai barrage were adequate for generating artificial flooding in most wetlands in the river system, a previous source of conflict in the drainage basin.
- For the Bhoj Wetland, high levels of heavy metals were shown to result from immersion of idols during religious festivities, an unlikely but significant source. Research was used to quantify the problem and show how a solution (moving the ceremony to another site) was possible.
- For the Aral Sea, scientific studies indicated that construction of a dam between the Small Aral and Large Aral seas could maintain the current (greatly reduced) size of the Small Aral given the reduced inflows, and with it, some of the lake's biodiversity and livelihoods for local people.

A Note on Modeling

The term "modeling" probably conjures up images of computers and mathematics for many readers. But models are not necessarily complex, mathematical or even run on a computer. Actually, they can be quite simple: anything that is a generalization of reality that used to gain deeper insight is a model. This section on "Use of Science" can, in fact, be thought of as a model: we proposed that science is used for three main purposes in lake basin management; we use case studies to test the "model"; we hope the "model" will

Box 8.1. The Value of Long Term Monitoring and Simple Modeling at Lake Naivasha

For over 100 years, Lake Naivasha in Kenya had attracted the attention of hydrologists, partly because of the extreme decade-to-decade changes in its surface area, and partly because it remained fresh even though there is no surface outlet. The first phenomenon was eventually explained as being the result of the shallow bathymetry of the lake coupled with climate variability, while the second was found to result from groundwater outflows that carried away dissolved salts.

The lake's water balance became more than a scientific curiosity when, in 1982, a vegetable grower successfully switched to raising flowers for the cut flower trade. This success rapidly led to much of the land around the lake being converted from grazing and cropping to intensive horticulture. By the early 1990s over 100 km² had been converted to grow flowers for the European cut flower trade. With this growth came an influx of workers. Water was abstracted from the lake, the local aquifers, and the inflowing rivers for the horticultural industry and for domestic use by the rapidly increasing population.

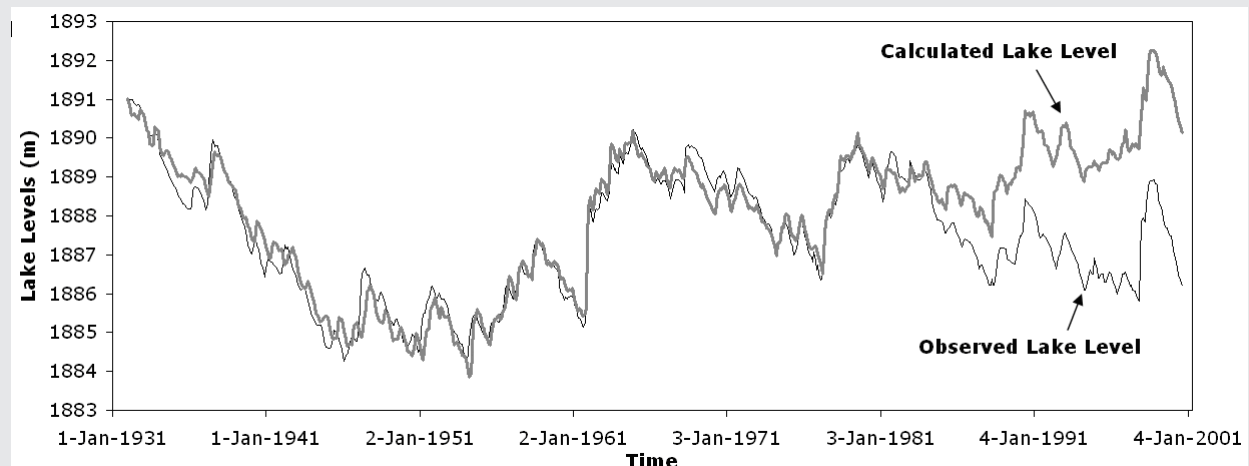
The Lake Naivasha Riparian Association (LNRA), representing landowners and others around the shores of the lake, feared that the lake's water was being over-used by this new development. They also were concerned about pollution of the lake and aquifers from agro-chemicals used by the horticulture industry. However, many horticulturalists did not believe that they were over-using the water resource and pointed out that the lake was higher than it had been in the 1950s prior to the development of their industry. They, in turn, formed the Lake Naivasha Growers Group (LNGG) to counter these and other claims about their industry.

In 1996 the LNRA asked the Ministry of Water Development to study the water balance and

the water related environmental impacts. This study was carried out in close collaboration with ITC in the Netherlands. This study was able to settle the issue of lake water use by developing a simple, spreadsheet-based water balance model of the lake and its catchment. The model required data on the inflows from the two major rivers; direct rainfall onto, and evaporation from, the lake's surface; and observed lake level and bathymetry. These data were available from a variety of sources—government and private sector—for a period from 1932 to the present day (some of the data, such as the local rainfall, were available from 1901).

If a groundwater outflow of 4.6 million m³ per month was allowed for, then the model was able to reproduce the observed lake level from 1932 to 1982 with remarkable accuracy (Figure 8.1). 95% of all observed monthly lake levels differed from the modeled levels by 0.52m or less over this period. This accuracy makes the growing discrepancy between the observed and the modeled lake levels after 1982 all the more striking. By 1997 the observed level was 3-4 m below that predicted by the model if there had been no abstractions.

Figure 8.1. Long-term water level change in Lake Naivasha.



This argument was strengthened by the coincidence between the onset of this decline in water level and the commencement of horticulture in the area in 1982, and the close match between the annual water deficit by 1997 (60×10^6 m³) and the estimated water use based on the area of horticulture and the crops grown.

These results are now broadly accepted by all within and outside the horticulture industry around Lake Naivasha as showing that the rapid development of the industry and the increase in domestic demand has had a significant impact on the lake level. The LNRA and the LNGG now work more closely together to promote a stronger conservation ethic amongst horticulturalists and to protect the lake's values. Apart from the results of the water balance study the LNGG understand the importance of their activities on the lake.

This conclusive result could not have been achieved without access to long-term reliable monitoring data. It was the closeness of fit between the modeled and the observed lake levels prior to 1982, as much as the steady divergence thereafter that added to the power of the results.

A second notable feature was the simplicity of the modeling. The spreadsheet-based water balance was simple enough to be transferred and used by the LNRA without requiring specialist modeling expertise.

Source: R. Becht and D.M. Harper 2002. *Towards an understanding of human impact upon the hydrology of Lake Naivasha, Kenya. Hydrobiologia* 488 1-11.

be used by readers to better understand the use of science at their own lakes.

The point is: a wide range of models has been used the lakes around the world; some are as simple as a thought in a decision maker's head like "Nutrients cause eutrophication; our lake is eutrophic; let's cut down on nutrient loading"; some are as complex as three-dimensional, time-varying, ecological-physical models. A complex hydro-dynamic model of circulation patterns was used to assess the likely benefits from different lake openings in Chilika Lake before the new opening was dredged to the ocean. On the other hand, a model was constructed of Lake Victoria but it has not proven useful to understanding the processes in the lake or been influential with decision makers because of its complexity and data demands. In the case of the North American Great Lakes, the issue of model complexity also was illustrated. Five different eutrophication models, ranging from simple phosphorus loading graphs to multi-dimensional, time-varying models, were used to determine the phosphorus target loads for the North American Great Lakes (GLWQA, 1978). Despite the range of complexity in the models used, however, they tended to converge on the same target numbers, implying that the simple models were sufficient. Lake Naivasha (Box 8.1) provides another example where a simple, spreadsheet models proved to be influential in management.

Overall, it is important that lake modeling efforts be tailored to the lake being modeled, including ensuring that the model is no more complex than is needed to meet the modeling objective. It is essential that the model design is driven by the managers and other stakeholders and not by the model developers. Initial brainstorming sessions between lake stakeholders and model developers can substantially facilitate this goal. Further, a model for a given lake should not be developed without the participation of local experts and officials in its development, as well as those ultimately responsible for its long-term use and refinement. In the absence of specific data and information for a lake being modeled, initiation of specific monitoring also may be required to obtain such data. A conceptual model developed at an early stage of a lake management project can help identify data needs and required sampling and monitoring efforts, thereby saving both human and financial resources.

It is noticeable how often simple models have proven successful. The lesson is not that simple models are best-it is doubtful if the Chilika Lake requirements could have been met with a simple model-but that the complexity of the model needs to be matched to the capacities of the users, the data available and the demands of the task. If the model development is driven by technological possibilities and not by the needs of the decision makers, then it is very likely that the model will not be used.

A Note on GIS and Remote Sensing

One of the emerging fields in lake basin management is the use of remote sensing technologies to provide wide coverage of otherwise hard-to-obtain information on both lakes and their basins. Additionally, Geographic Information Systems (GIS) are increasingly being used as a tool for managing and manipulating spatial information.

While these technologies often require funds for acquisition of data, the purchase of expensive computers and software, and extensive training for operators, they have seen use not only in developed countries but also developing countries. Gyllenhammar shows how remote sensing, GIS and modeling were all used to contribute important knowledge on the management of Lake Kyoga (Uganda) and its basin. Furthermore, Bradt provides some basic discussion on both the possibilities and the limitations of remote sensing for lake basin management.

"Non-use" of Science

Many cases show how a *lack* of scientific information can constrain the decision making process. There are a number of cases where science could have been used effectively, but was not. For example, the LBMI lake briefs cited the need for scientific studies to show:

- The effects of climate change versus local water withdrawals on lake levels in Lakes Chad and Baringo;
- The limits to grazing in Lake Baringo;
- The limits of irrigation on Lake Chad and the Aral Sea;
- The effects of aquaculture on Lake Toba;
- The effect of future upstream dams on Tonle Sap; and,
- The effects of siltation/nutrient loading, before it becomes a major problem, at Lakes Malawi and Tanganyika.

The LBMI briefs also show how scientific knowledge may have influenced policies before they were implemented. Examples include:

- Health problems resulting from the unexpected release of airborne particles from the exposed lake bed of the desiccated Aral Sea;
- Ecological studies might have shown the detrimental effects from lowering the level of Lake Sevan for hydro-power and irrigation; and,
- The effects of soil erosion and nutrients from human wastes on the eutrophic status of Winam Gulf in lake Victoria may have been better appreciated by decision

makers if scientific studies had been carried out some years ago.

While the LBMI briefs do not speculate on why scientific studies were not carried out in these and similar cases, it is possible to use experience from scientific input to management in other fields to suggest the causes. First, decision makers often see scientific inputs as time-consuming, expensive and inconclusive when they need to make decisions quickly. It can be as difficult to persuade scientists that an imprecise but timely answer is required as it is to persuade decision makers that a delay of a year while waiting for factual information can be highly cost-effective in the long-term. Secondly, scientists are often poor communicators with both decision makers and stakeholder groups. They can have difficulty in expressing their findings in ways that have meaning to non-scientists. Thirdly, it can be very difficult to get scientists from disciplines as diverse as sociology and hydrology to work together. This integrative approach to scientific studies is particularly necessary in understanding lake basins where so many processes (terrestrial and aquatic; biophysical and socio-economic; physical and ecological) interact. Finally, it is worth stating that these typical difficulties affect scientific studies in the developed world as much as they affect the developing world.

Value of Monitoring

Without carrying out special scientific studies or developing models, simple monitoring of a lake and its basin can provide valuable insights into a lake's baseline condition, its change over time including the effects of a given policy.

To assess baseline conditions

One key purpose of monitoring is to understand the baseline or "normal" conditions of a lake in order to inform policy. Such monitoring programs are usually in place in developed countries and also sometimes in developing countries such as at Laguna de Bay in the Philippines. Two other examples from developing countries illustrate the value of baseline monitoring:

- The Lake Nakuru case shows that the monitoring data demonstrate the high degree of natural variation that can occur in the lake's water levels due to high levels of evaporation and water abstractions, as well as influences from more global phenomena, such as global climate change. All are causing dramatic changes in the lake's limnological characteristics. By having information on this natural variation, decision makers are better positioned to recognize and evaluate the impacts on the lake from human activities in its drainage basin.
- Monitoring data collected over the past several years at Lake Ohrid suggest that both the phytoplankton and zooplankton communities in the lake are changing,

consistent with the increasing eutrophication of the lake. This baseline monitoring makes it unequivocally clear to the basin communities that there is a need to control nutrient loads to the lake.

While long-term monitoring is most desirable for providing a baseline, even short-term, historical studies can also prove valuable. For example, Talling's work on Lake Victoria in 1961 provides an invaluable baseline on the condition of the lake almost 50 years ago and has been used in recent times to show that the lake has changed dramatically from a diatom-dominated to a cyanobacterially-dominated lake. In another example, various studies on the endemic species of Lake Dianchi in the 1950s, have proven useful in understanding past conditions in that lake and on the need for biodiversity conservation.

To assess effects of a policy

Decision makers need monitoring of a lake's condition after the implementation of a policy change, to properly evaluate the effectiveness of the policy. When evaluating policies, it is important to use a with/without project (policy) analysis. The Lake Dianchi case shows how, even though the pollution load to the lake has increased in recent years, policies have led to a divergence between the load generated at source, and the load entering the lake. Without good information on loading, the current policies would probably be declared a failure, when in fact they have had a positive effect. The Lake Titicaca case shows that monitoring made it possible to establish clear priorities during the execution of the Master Plan for Flood Prevention and Resource Management in the basin. On the other hand, the Lake Chad case indicates that, because of the absence of international monitoring bodies, past agreements on the conservation and development of basin resources could not be enforced, resulting in detrimental impacts on the lake ecosystem.

What to monitor

Experience in monitoring lakes around the world has demonstrated that some parameters that are relatively simple-to-measure can provide a great deal of insight into the condition of a lake and its resources. A list of fundamental in-lake parameters is provided in Box 8.2. Although many additional in-lake and laboratory measurements can be very helpful (e.g., types and numbers of different algal species; composition of rooted plants), the list in Box 8.2 can provide a reasonably accurate picture of the major problems facing a lake. However, it will not necessarily indicate the sources of these problems. Because the lake drainage basin is the place where human activities occur, and the root causes of most lake problems, information on drainage basin characteristics may also be needed to help identify sources of lake problems.

A Note on Serendipity

Long-term monitoring, even when carried out without an immediate purpose, can have serendipitous effects. For example, the Lake Biwa experience highlights how long-term records of parameters as diverse as snowmelt, temperature, and dissolved oxygen in the hypolimnion all subsequently came together to give indications about the potential effects of global warming on the lake. The North American Great Lakes shows that both formal and informal data sets “become invaluable in monitoring and interpreting ecosystem changes often unrelated to the purpose for which the data were originally collected.”

Sharing Information

The Lake Nakuru case discussed above illustrates an important point: the need ensure that research and monitoring findings are available in simplified language that decision makers and resource users can understand. The key lesson learned is that the value of science and monitoring as information for policy makers evaporates if the results and their meaning are not properly transmitted. Some ways in which information can be successfully shared include the following.

Use of Indicators

While some of the parameters presented in Box 8.2 are easily understood by the public and decision makers, many are not. Transparency is a fairly easy concept (the less “stuff” in the water, the clearer it is; therefore, the deeper one can see into the water); In contrast, the Chemical Oxygen Demand is not. In fact, even professionals can make mistakes about the type of COD measured (e.g., was the oxidizing agent manganese or chromium?). To make the sharing of information as easy as possible, many of the lakes in this study have developed “indicators” of various types of describe lakes or basin conditions.

For example, the development of easily understood indicators has been the subject of major biennial conferences in the North American Great Lakes basin (described in Box 8.3). For Laguna de Bay, the Laguna Lake Development Authority has shown considerable progress in presenting water quality data in a simple schematic diagram called the Water Mondriaan. Inspired by the work of Piet Mondriaan, a famous Dutch painter, it presents technical information in the form of simple lines and colors in an easily understood format for the public and decision-makers. For its International Waters Projects, the GEF has developed a suite of indicators (process indicators, stress reduction

Box 8.2. Easily obtained parameters for evaluating lake conditions

- Water flushing rate: The faster the flushing rate, the faster a pollutant will be flushed from a lake (assuming the pollutant input has been reduced or eliminated). This is a function of both lake volume (how much water the lake contains) and the water inflows and outflows (the rate at which water enters and leaves a lake, including that lost to evaporation);
- Water transparency: The clearer and more transparent the water, usually the better the water quality;
- PH: This is a measure of the acidity of water. Fish cannot survive above a certain level of acidity;
- Specific conductance: A measure of the quantity of dissolved minerals (e.g., calcium, magnesium, sodium, potassium) in the water, typically the higher the specific conductance, the higher the mineral concentration;
- Dissolved oxygen concentration: The lower the oxygen concentration in the water, the greater the likelihood the oxygen-consuming organisms (especially fish) will be affected. Further, a low oxygen concentration can accelerate the release of nutrients from sediments at the bottom of lakes;
- Biological oxygen demand (BOD) and chemical oxygen demand (COD): These tests provide information on the possibility of pollution from organic substances. A special concern exists in regard to synthetic organic materials (DDT, PCBs, dioxin), which are carcinogenic and can bioaccumulate in the tissues of aquatic and terrestrial organisms, including humans.
- Nutrients: Phosphorus (and nitrogen in some cases) is considered to the nutrient controlling or limiting the maximum biomass of algae and aquatic plants. The higher the concentrations of the biologically-available forms of these nutrients, the greater the potential for nuisance algal blooms and other eutrophication symptoms in a lake;
- Temperature: This parameter has important implications for the physical structure of the water column, as well as maintenance of aquatic life (especially fish). Temperature also controls the rate at which various biophysical and chemical reactions occur;
- Chlorophyll concentration: As a measure of algal biomass (quantity), the larger the chlorophyll concentration, the greater the possibility that the lake will experience nuisance algal blooms and other eutrophication symptoms.
- Heavy metal concentration: Certain heavy metals, particularly those that can bioaccumulate in the tissues of aquatic and terrestrial organisms, including humans (e.g., lead, mercury), are toxic. The higher the concentration, the greater the potential for negative impacts.

indicators, environmental status indicators) which are flexibly applied and can allow for easy evaluation of project progress (Duda 2002).

Museums and Information Centers

Lake-based museums or centers are another useful way to ensure that scientific and other types of information are widely disseminated. One example is the realization of a Lake Science Center established at Barkul in the Chilika Lake basin for hydrobiological and other studies during 1999-2002. At Lake Champlain, the value of developing a lakefront laboratory and science museum (Leahy Center) as a means of fostering effective lake management within the drainage basin is highlighted. The Lake Biwa Museum is a long-standing and very successful example of a lake science center devoted to disseminating of information and data about the lake and its problems. Based in part on these successes, establishment of a Lake Resource Centre (LRC) at the Bhoj Wetland was included as part of large international project.

Involving People

Finally, many of the case studies show the benefits of directly using people to gather and provide information on lakes. Examples include the following:

- An interesting example of information gathering by citizens is the "Firefly Monitoring" in the Lake Biwa drainage basin. Akanoi Bay, which feeds into the South Basin of Lake Biwa, used to be famous for fireflies. Changes in landscape (mainly the channeling of rivers and loss of natural habitats), however, have led to a decline in the number of fireflies. A local NGO implemented various restoration projects, with one key indicator of success being an increase in the number of fireflies—a simple, but effective, indicator of restoration progress.
- In Lake Victoria, water hyacinth expansion and control are carried out and monitored by local fishing communities, who are the ones best placed to carry out such work.
- The Lake Tanganyika case shows the importance of involving the local communities in data collection. It is noteworthy that there are questions about the extent of this involvement, since the collection of water samples or reading of water/rain gauges may not be appropriate for communities that are not trained to undertake such tasks.
- The Lay Monitoring Program in lake Champaign has conducted lakewide monitoring of eutrophication parameters using citizen volunteers every year

Box 8.3. Evolving Indicators: The State of the Lakes Ecosystem Conference (SOLEC)

The purpose of the U.S.-Canada Great Lakes Water Quality Agreement (GLWQA) is "to restore and maintain the physical, chemical and biological integrity of the Great Lakes Basin." To evaluate the effectiveness in meeting this goal, the Environmental Protection Agency and Environment Canada biennially host a "State of the Lakes Ecosystem Conference (SOLEC), to report on the state of the Great Lakes ecosystem and the major factors impacting it, **including environmental and socioeconomic indicators for assessing these factors**. SOLEC also provides a forum for information exchange and discussion among people in all levels of government, corporate and not-for-profit sectors that make decisions affecting the Great Lakes. To date, five SOLEC conferences have been held.

- SOLEC 1994—The first conference addressed the entire lake system, emphasizing aquatic community health, human health, aquatic habitat, toxic contaminants and nutrients, and the changing Great Lakes economy;
- SOLEC 1996—This conference focused on areas where biological productivity was greatest and humans had maximum impacts, including nearshore waters, coastal wetlands, lakeshore lands, impacts of changing land use, and information availability and management. Also recognized was the need for a comprehensive set of indicators to allow the governments to report on progress made under the GLWQA in a predictable, compatible and standard format;
- SOLEC 1998—This conference focused more formally on the indicator development process, with development of a suite of easily-understood indicators that objectively represented the condition of the Great Lakes ecosystem components, as called for in the GLWQA;
- SOLEC 2000—This conference reported on the state of the Great Lakes on the basis of 80 science-based indicators developed since SOLEC 1998. It also introduced a new group of "Societal Indicators," which seek to measure both human activities impacting the environment, and the societal action(s) taken in response to these environmental pressures;
- SOLEC 2002—This conference continued to update and assess the state of the Great Lakes, focusing on 43 indicator assessments used to provide the most comprehensive analysis to date of the Great Lakes Basin Ecosystem. It also presented a candidate set of "Biological Integrity" indicators, as well as proposed indicators for agriculture, groundwater, forestry and society responses, which, as a part of the "Societal indicator" suite, measure positive human responses to ecosystem pressures.

Work continues on the Great Lakes indicator suite, including efforts to streamline the reporting requirements of the GLWQA, and to report progress under it within the context of management challenges and actions. Further information on the SOLEC indicators can be found on the website: <http://www.epa.gov/glnpo/solec/>

since 1979. The information collected by these citizen monitors has been used to develop state water quality standards.

Organizing/Carrying out Science and Monitoring

In an ideal world, with no shortage of funding or and trained staff, each lake basin would have a resident institute-recognized for its capabilities and impartiality-carrying out both required and elective research and monitoring and coordinating information gathering between various sectors. This actually is close to reality for some of the survey lakes. Where funds are scarce, however, we see fragmentation and a reliance on international funding-not necessarily problems, but also not ideal.

Resident Institutes

Lake Champlain (along with Lake Biwa and the North American Great Lakes) provides an example of just how important and effective a role science and monitoring can play. The Lake Champlain Basin Program has always sought to base planning and policy decisions on sound scientific information. Without this strong foundation in sound science, a watershed management program will not necessarily produce the desired outcomes. Nearly two dozen representatives from the technical community throughout the lake basin have been brought together in a Technical Advisory Committee (TAC) to examine the scientific issues of every major policy question, and provide policy and budget guidance to the Steering Committee each year. The TAC also reviews research and implementation projects to ensure both scientific merit and successful conclusion. Moreover, it is chaired by a non-governmental scientist who also holds a seat on the Lake Champlain Steering Committee. When scientific information is not adequate to guide a management decision, the LCBP allocates funds to support focused and timely research or monitoring to address the knowledge gap. This effort, however, does not come cheap. Monitoring environmental conditions in the lake basin typically requires up to \$300,000, a sum of money usually not available for most lakes.

Internationally funded programs

For lakes in developing countries without the ability to maintain resident programs international studies and funding can play an important role. For example, lakes like Malawi, Victoria and Tonle Sap have received much attention from foreign scientists and the information gathered has been used in decision making.

Several cases indicate the need for local training and ongoing support to ensure the sustainability of such internationally-funded programs. In Lake Tanganyika for example, except for the CLIMLAKE project, all the training conducted only led to certificates, rather than higher degrees. In

such situations, the riparian states are forced to rely heavily on expatriates to undertake tasks which would otherwise have been undertaken by local experts. The Laguna Lake Development Authority (LLDA) provides a contrary example, in which local ability was well supported and developed.

Fragmentation

The Lake Toba LBMI brief illustrated the shortcomings when the agencies conducting various research projects did not readily communicate with one another. Instead they kept much of their results and data to themselves for reasons of prestige and dominance. As a result there is no sound, comprehensive research project covering the major aspects and concerns of the lake.

The same problem arises between countries. In the Lake Xingkai/Khanka case it was shown that, although China and Russia developed their own monitoring and information management systems for the lake, a lack of adequate technical and institutional capacity to collect, analyze and store relevant data has prevented harmonized and cost-effective management for the transboundary environmental issues. A UNEP Diagnostic Analysis brought teams of Chinese and Russian scientists together to produce a definitive document. The GEF's Transboundary Diagnostic Analysis (TDA) process has helped countries exchange information and work together in several of the study lakes (e.g. Lake Titicaca and the Caspian Sea).

How much information is enough?

Like money, no amount of information ever seems to be enough: almost every case cites the need for more information, for more research, for more monitoring. Even in cases where a tremendous amount of money has been spent on information the call is unambiguous. The Lake Champlain LBMI brief states that additional research and monitoring efforts are needed to better understand the sources and effects of toxic pollutants in the Basin, whilst the Lake Biwa LBMI brief states that the funds wasted for the lack of a scientific approach in managing the lake far outweighed the required investment-another clear call for more scientific information.

One lesson learned from this chapter is that the lack of information should not impede action. The Laguna Lake Development Authority (LLDA) has adopted the slogan "Ready, fire, aim!" for good reason. The LLDA has not been paralyzed by incomplete information; instead they have learned while acting and, as a result, have been successful in their management efforts.

Finally, acquiring a sufficient level of information does not necessarily have to be prohibitively expensive: the Lake Nakuru experience shows the development of a cost-effective package of practices for environmental monitoring,

noting that it is not likely to cost more than 1% of the annual revenue generated at the Lake Nakuru National Park in which the lake is located. A checklist of the essential information and data for lake management is given in Box 8.4

Key Lessons

Some of the key lessons from the implementation of technological methods at lakes around the world include:

- Information is costly and never complete so lack of complete information is not a reason for delaying action (note LLDA's "Ready, fire, aim!")
- Local knowledge is often overlooked but can be invaluable; make efforts to tap this source.
- Sharing and utilizing the collective knowledge base for lake management requires ensuring that all relevant stakeholders are involved at the beginning in identifying lake problems and helping to formulating realistic solutions for them.
- Information not properly "translated" into the language of decision makers and stakeholders is wasted.
- Resident scientific institutions are better than teams of scientist brought in for short-term studies. The nature of lakes (long water residence times and complex dynamics) makes long-term commitment particularly valuable.

- The entire lake basin, not just the lake itself, must be a part of any monitoring program.
- Keep things simple: Simple models can often provide management information equal to that obtained from complex models.

Further Reading

1. [Bradt](#) provides an introduction of the possibilities and the limitations of remote sensing for lake basin managers who do not have much experience with the topic.
2. [Gyllenhammar](#) shows how remote sensing, GIS and modeling were all used to contribute important knowledge on the management of Lake Kyoga (Uganda) and its basin.
3. [Rast](#) gives a general overview of informational requirements of a lake basin management program.
4. [Robarts](#) makes a case for why global-scale monitoring of lakes and reservoirs is of importance for the international community as well as stakeholders in individual lake basins.
5. [Verma](#) provides a case study of how economic valuation is carried out in developing countries (India) and some lessons on how such information can be "put on the agenda" of decision makers.

Box 8.4. The Information Bare Essentials: A Checklist for Decision Makers

- **Scientific/Technical Prospects and Options**-What is the current condition of a lake (i.e., current water quantity and quality, and changes in them over time)? What is the status of its biological communities? What are the root causes, within and outside the lake drainage basin, for the observed problems? What are the lake management options and what are their possible outcomes? How can progress in lake recovery be evaluated? What is the expected degree of, and recovery time frame for, specific lake problems?
- **Sociological Perspectives**-What is the cultural history of lake use in its drainage basin? What customs, social mores or religious beliefs influence the use of lakes and their resources? To what extent can the public and other lake stakeholders be mobilized to help identify and implement effective lake management efforts?
- **Economic Characteristics**-What are the economic characteristics of the drainage basin stakeholders, including the relevant governmental management bodies? Are sufficient financial resources available for sustainable management interventions? Is poverty alleviation linked to sustainable lake use? What economic incentives, penalties or subsidies exist to facilitate lake management interventions and what are their past experiences?
- **Institutional and Legislative Frameworks**- What is the existing legislative framework in the drainage basin? Do adequate institutions and laws exist to regulate, protect or guide the sustainable use of a lake and its resources, or are new or modified ones needed? Do different lake management institutions have overlapping or conflicting mandates? Are existing laws and regulations enforced in a consistent, equitable manner? What other legislative incentives exist and what are their experiences?
- **Political and Governance Structures**-What are the political realities regarding the sustainable use of lakes and their resources within the lake drainage basin? Is the political structure amenable to public inputs? Are current politicians and government officials providing the necessary leadership to facilitate needed lake management interventions? Is the lake governance process transparent, equitable and accessible to the public and other lake stakeholders?