Chapter 7

Technological Responses: Possibilities and Limitations

Changing people's behavior is not easy. Whether it is done by making rules or creating incentives or by internalizing new values through education and raising awareness, it is a challenge. Decision makers know this. And that is why one of the first responses to a problem at many of the lakes in the LBMI study is a technological response-a "quick fix"-one that tries to alleviate a problem, often not by addressing the root causes, but by engineering a solution.

Sometimes these technological responses can have profoundly positive effects on lakes. Below, we will look at cases where measures like sewage treatment, dredging, and the biological agents have increased lake values. One of the key lessons, however, is that technological responses on their own are not sufficient and is the main reason why we see a range of other policy responses.

This chapter examines "technical" conservation/remediation interventions that help protect a lake's values and does not discuss development interventions such as fish pens and hydropower dams. The technological responses described here can be broadly divided into two groups: watershed-based measures (which include point and non-point measures) and in-lake measures (which include biological, chemical and physical measures).

The examples used below are based on the technological interventions seen in the 28 LBMI lake basin cases and are augmented with some newly commissioned studies for these JICA materials (shown in hyperlink and Further Reading).

Watershed-based Measures

Point-source Control

Wastewater Diversion

One simple way of avoiding the negative effects of wastewater on a lake is to divert it outside of the basin so that it never reaches the lake. Over 100 years ago-to combat typhoid and cholera outbreaks-the wastewater of Chicago was diverted from Lake Michigan by an engineering project that reversed the flow of the Chicago River from its original direction to Lake Michigan to the Illinois River/Mississippi River system. This effectively removed the huge city of Chicago, located on the shores of Lake Michigan, from the drainage basin of the North American Great Lakes. However, while it took care of the pathogen problem in Lake Michigan, the water quality of the Illinois River and Mississippi River suffered as a result. Similar diversions of sewage have been carried out in the Bhoj Wetland case to control nutrient inflow as well as to minimize microbial contamination of this drinking water source. Diversion of sewage may become an option at Lake Dianchi, but only after completion of another diversion project-one that brings water from outside the Dianchi basin into the basin for use in Kunming city. The reason is that without the incoming diversion, the water balance in the basin depends heavily on the irrigation return flows and re-use of domestic sewage, so exporting sewage was, until recently, not an option because of the need to keep scarce (yet polluted) water resources in the basin.

In addition to the Lake Michigan and Bhoj Wetland, there are two classic cases of sewage diversion in the literature. In the 1960s sewage was diverted from Lake Washington (near Seattle in the NW United States) to the Puget Sound, which as part of the ocean, was thought to have higher assimilative capacity. As a result of the diversion, the lake went from a eutrophic to an oligotrophic state due to lower nutrient loading, making Lake Washington a well-known lake that had been "saved". A similar scheme was carried out at Lake Tahoe (on the California-Nevada border in the Western United States). Even though the sewage flowing into Lake Tahoe had been treated at an advanced level, the remaining nutrients were still high enough to pose a problem for this ultra-oligotrophic lake. The sewage was diverted out of the basin into a constructed impoundment.

The key lesson learned from these examples is that wastewater diversion can have a positive effect on a lake from which the sewage is being diverted, but it is important to consider potential negative effects on the area receiving the new pollution load. That may indeed be preferable in cases when a valuable lake resource is being saved is greater than the costs being incurred elsewhere, including the losses suffered by people not well represented in the decision-making process.

Conventional Wastewater Treatment (Primary and Secondary Treatment)

Directly treating wastewater before it gets to a lake is another major response to lake problems, and one that actually addresses the root causes. This sub-section, and the two that follow, look at three major types of wastewater treatment found in the cases: conventional wastewater treatment (for pathogen and organic removal), advanced wastewater treatment (for nutrient removal) and industrial wastewater treatment (for toxic removal).

Conventional wastewater treatment is traditionally divided into primary and secondary treatment. Primary treatment involves mainly physical means of treating wastewater, such as sedimentation tanks, whereas secondary treatment usually employs microorganisms to degrade organic material in the sewage, by processes such as activated sludge or trickling filters. Conventional treatment is usually carried out at centralized locations that are connected to sewerage pipes that bring in the sewage from surrounding domestic sources, although on-site treatment is common in areas with low population density. Conventional treatment removes many pathogens and much organic material thereby alleviating problems related to pathogenic contamination and low dissolved oxygen levels due to high organic loading. However, as discussed in Chapter 2, in many cases, the main motivation for constructing a conventional wastewater treatment system is the amenity and direct health benefits of sanitation it provides to users-regardless of the positive effects it may have on a lake. Box 7.1 summarizes the use of conventional and advanced wastewater treatment in the 28 LBMI cases.

Muhandiki gives a discussion on how conventional treatment systems have been applied in Africa (Lake Nakuru, Kenya) and Asia (Bhoj Wetland, India). That paper considers the lessons learned, especially on the need for planning and maintenance. Magadza provides a sobering case of how similar treatment (including nutrient removal---discussed next) successfully reversed the eutrophication of Lake Chivero, Zimbabwe, yet how population growth and maintenance problems overwhelmed the system, sending the lake into a hypertrophic state.

Advanced Wastewater Treatment (Tertiary Treatment)

Advanced wastewater treatment, as discussed here, is simply enhanced nutrient (N, P) removal at conventional wastewater treatment plants. The purpose is to cut down on the load of nutrients to a lake to prevent or control eutrophication. While conventional treatment removes a small percentage of nutrients in sewage, advance treatment such as chemical precipitation and nitrification/denitrification can achieve up to 95% removal of nutrients. Advanced treatment requires both conventional treatment to be in place and additional funds for construction and operation; therefore, it is usually carried out only in high-income economies like those in cells III-1 and III-2 of Box 7.1. In 28 LBMI cases, only Lakes Biwa, Champlain, Constance, Dianchi and the North American Great Lakes have extensive advanced treatment facilities in place. However, in those cases, advanced treatment has profoundly reduced the load of phosphorus to the lakes, a root cause of eutrophication.

Box 7.1. Conventional and Advanced Wastewater Treatment at the 28 LBMI Study Lakes

Ide (2004) analyzed the extent of sewage treatment at the 28 LBMI lakes based on per capita gross national income (GNI) and population density. The results are summarized in the table below. The extent and degree of wastewater treatment is indicated by the **bold** words in each cell (e.g., **Low to High**). The classes of treatment are indicated as **low** = primary, **medium** = secondary, and **high** = tertiary. For lake basins with low population density and low GNI per capita (cell I-1), almost no sewage treatment is carried out. As both income and density increase (I-2, II-1, II-2), conventional treatment systems expand, usually with bilateral funding. For high GNI per capita countries (III-1, III-2), even in sparsely populated areas (III-1) conventional and advanced treatment are carried out, usually with central or local government funding. A full discussion can be found in Ide (2004) on the CD-ROM.

Population Density / **GNI per capita**	**1) < 100 person/km²**	**2) >= 100 person/km²**
I) Low-Income Economies < US$736	I-1) Malawi, George, Tonle Sap, Issyk-Kul, Chad, Kariba, Tanganyika, Baringo, Chilika **Rare or Low**; Even not in plan	I-2) Victoria, Naivasha, Nakuru, Bhoj Wetland, Toba **Low to Medium** (in urban area) Funded by bilateral assistance
II) Middle-Income Economies US$736 - US$9,075	II-1) Aral Sea, Baikal, Titicaca, Ohrid, Xingkai/Khanka, Tucurui, Peipsi/Chudskoe, Cocibolca **Low to Medium** Partly funded by bilateral assistance	II-2) Dianchi, Laguna de Bay **Low to High** Funded by bilateral or the central government's assistance
III) High-Income Economies > US$9,075	III-1) Champlain, Great Lakes **High** Funded by the central and local governments	III-2) Constance, Biwa **High** Funded by the central and local governments

Source: Ide (2004)

Industrial Wastewater Treatment

While industrial wastewater can be a source of organic matter and nutrients to a lake, one of the main reasons for industrial wastewater treatment is to prevent toxic contamination. The extent of industrial wastewater treatment is similar to advanced wastewater treatment (discussed in Box 7.1) with some exceptions. Extensive treatment with strict effluent standards is in place at Lakes Biwa, Champlain, Constance, Dianchi and the North American Great Lakes. This treatment removes toxics as well as organic matter and nutrients before it can reach the lakes.

At Lake Baikal, the only significant source of industrial wastewater to the lake-a pulp mill-is installing a closed wastewater treatment system to control release of organocholide compounds to the lake. Plans to control toxic effluents have been proposed for Lakes Naivasha and Nakuru but are yet to be carried out. There is a special program in place at Laguna de Bay that charges industries for the amount of organic matter (BOD) they discharge to the lake. This has lead to a sharp drop in organic loading to the lake (see also Chapter 5 on Policy for discussion).

In some cases, such as the Russian side of Lake Xingkai/Khanka or Lake Sevan, economic downturns can lead to a drop in industrial wastewater loads-an example where factors exogenous to the lake basin itself van have a great influence on the lake.

The main lesson regarding industrial wastewater treatment comes from the cases where it was *not* carried out. In general, when there was a large release of toxic in a lake basin, the three characteristics of lakes make clean-up a huge undertaking. Long retention time means that toxic chemicals in a lake are not flushed and stay in the system for a long time. Complex dynamics means that the chemicals often biomagnify, creating both ecological damage and risk to humans. Integrating nature means that the problem cannot usually be contained to a small area but tends to spread. As discussed latter in this chapter, various remediation methods exist, but all are more expense that proper treatment in the first place.

Nonpoint Source Control

Point source control is one of the first technological responses to lake problems, but even in cases where it has been considered successful, nonpoint sources of pollutants often remain uncontrolled and contribute to persistent problems. The Lake Biwa, Champlain, Constance and North American Great Lakes Briefs all cite nonpoint sources as the main challenges facing those lakes. The difficulty

Box 7.2. Timing of Water Supply, Conventional and Advanced Wastewater Treatment Development

The cases of Lake Constance, Lake Biwa and Lake Nakuru provide contrasting examples of the timing and methods of how infrastructure like water supply, conventional wastewater treatment and advanced wastewater treatment are developed.

For Lake Constance, people in the lake basin have had water supply service for more than one hundred years. Installation of a sewerage system came much later than the completion of the water supply system. In 1972 only 25% of all inhabitants in the catchment area were connected to sewage plants with biological (conventional-secondary) treatment. However, the percentage has increased rapidly since reaching 90% in 1985 and over 95% in 2001. At the same time, the percentage of biologically-treated sewage that is also treated with phosphorus removal systems (advanced) increased from 24% in 1972, to 88% in 1985, and to 97% in 2001.

The population coverage of water supply at Lake Biwa basin was about 30% in the 1950s, but in step with high economic growth in Japan, the percentage increased rapidly and reached 80% in the 1960s. However, sewage treatment systems covered only 4% until the 1980s. Drastic expansion of the sewage system in Shiga started in the early 1980s, and current coverage is now around 70%. Interestingly, because the construction of sewerage and sewage treatment was relatively "late", both conventional and advanced treatment systems were constructed together from the beginning. Today, the percentage of advanced treatment in Shiga is the highest in Japan.

In sharp contrast to the above two lakes, a full scale water supply system was first installed in the catchment area of Lake Nakuru in the early 1990s. As a result, the old sewage treatment plant (conventional) became unable to treat the volume of newly generated wastewater, and much wastewater began to come into the lake without treatment. To solve this problem, a large-scale improvement project of sewage system started at Lake Nakuru several years later. However, no advanced treatment has been installed yet. Additionally, connection to the upgraded plant has not been completed and it is running well under capacity. This illustrates the necessity of a multisectoral plan that considers the development of water supply system together with sewage system.

In short, water supply, sewage, and advanced treatment systems were adopted in stages at Lake Constance as well as other lakes in most developed countries. However, both sewage and advanced treatment systems were introduced simultaneously at Lake Biwa after the completion of water supply system. Even though Lake Nakuru had the above-mentioned problem and does not have advanced treatment yet, it achieved the development of water supply and sewage system almost at the same time. These facts imply that, if financial arrangements are available, there is a possibility to develop those three systems simultaneously although stepwise implementation of environmental infrastructure is more realistic and common. The development of environmental infrastructure in a multisectoral manner would be more desirable to achieve long-term goals for lake management.

Source: Ide (2004).

in controlling nonpoint sources, which include agriculture and urban runoff, is that sources cannot be readily identified (complicating regulation and enforcement) and usually are related to precipitation events and therefore quite variable. The problem of nonpoint source pollution is compounded in many lake basins by the destruction of littoral wetlands, areas that typically moderate nonpoint inputs to a lake by serving as a sort of "filter".

Recycling and Reuse of Agricultural Runoff
One of the growing fields in nonpoint source control is the control of runoff from agricultural fields. In particular, this technique has been applied in developed countries such as Japan and USA. The main benefits are two fold: release of water with nutrients and/or pesticides to the environment is lowered, hence alleviating associated problems such as eutrophication; water, nutrients and/or pesticides are recycled, leading to lower costs for agricultural production. Watanabe provides a detailed look at two systems in Japan and the USA for rice fields.

Constructed Wetlands
Almost all the 28 LBMI lake briefs indicate some degree of human encroachment on littoral wetlands. This usually results from development of lakeshore areas (urban sprawl at Lake Champlain, construction of roads at Lake Biwa) or reclamation of wetlands for farming or grazing. One simple way of reducing nonpoint source loads to a lake is to rehabilitate these wetlands. An additional benefit is that rehabilitation helps conserve and restore biodiversity. Some of the more detailed efforts include:

- The Lake Ohrid Brief describes how the 2003 "Transbouandary Watershed Action Plan" signed by riparian countries provides for habitat protection and restoration through wetlands inventory and the establishment of a no-net-loss policy.

- The Lake Chad Brief provides a good example of rehabilitation of the Logone wetland in Cameroon in 1993. The embankments of the barrage along the river were modified over eight years. Stakeholders and local community members were involved in the planning and design of the project.

- The Lake Champlain Brief details how the Lake Champlain Basin Program sponsored a wetland acquisition strategy that laid the groundwork for a four-phase, multiyear program to permanently protect almost 9,000 acres of wetlands in the Champlain Valley. By 2001, $1.4 million in federal funds had been provided to the project, which had conserved 4,000 acres of wetlands and surrounding areas in the Basin.

- The Lake Naivasha Brief shows how several of the larger farms in the basin have looked at ways of improving their impact on the environment by using integrated pest management to cut down on pesticides and using constructed wetlands to treat their wastewater.

- The Aral Sea Brief illustrates international efforts by the GEF and World Bank to restore wetlands on the lower Amu Darya delta.

The main lesson learned, especially for lake basins where wetlands are still in their natural condition, is that wetland protection should be a top priority. If wetlands are lost, the cases show that there will be an imperative in the future to replace them; therefore, it is much more cost effective to avoid destruction in the first place. The activities of the Ramsar Convention, the major international effort to promote wetland conservation and restoration, are detailed in Box 7.3.

Reforestation
Like the destruction of wetlands, loss of forest cover in a lake basin also invariably has negative effects on a lake, usually by increasing land erosion and sediment transport. Reforestation schemes (replacing destroyed forests) are discusses in the Baikal, Chad, Laguna de Bay, Nakuru, Ohrid, Tanganyika and Toba Briefs. Afforestation schemes (to plant forest where it did not exist before) are described in the Baringo, Bhoj Wetland and Chilika Briefs. Once again, the key lesson learned is that it is better to preserve the original resource than to restore it, as will inevitably be necessary.

In-Lake Measures

Biological Measures

Predators
Biological measures can be used to control either introduced nuisance species, such as water hyacinth, or problematic outbreaks of endogenous species, such as excessive blooms of cyanobacteria. A major reason why introduced species are often so successful in new environments is because they are no longer faced with their natural enemies. Thus, when Water Hyacinth is introduced (unintentionally) to a lake where these pathogens and predators are absent, and where other conditions are favorable (temperature, nutrients), then the growth can be explosive. These enemies of the invasive species' can be introduced in order to control their rampant growth.

For example, at Lake Victoria two species of weevils (*Neochetina eichhornia* and *Neochetina bruchi*) have been used successfully to combat serious infestation of Water Hyacinth. Extensive research was conducted prior to the release of the weevils to show the weevils would be Water Hyacinth-specific and would not result in another uncontrollable distortion of the ecosystem (as occurred after the introduction of the Nile Perch in the 1950s). The weevils have been successful in controlling the Water Hyacinth infestation in this lake, although the reduction in the weed was probably assisted by a period of extreme weather. The traditional fishing communities have been successfully engaged in raising and releasing the weevils for water hyacinth control, so the program can be expected to sustain itself.

In Lake Kariba, grasshoppers (*Paulinia acuminata*) were used to control excessive growth of the invasive Kariba Weed (*Salvinia molesta*). The effect of these predators, along with generally dropping nutrient levels, has been credited with the weed's decline.

The Lake Naivasha case notes that Kariba Weed has been on the lake since 1962 and by the early 1970s it had become a major ecological problem as it covered a large portion of the lake. After chemical control (see below) failed, a biological control agent *Cyrtobagus salviniae*, a host-specific insect, was introduced and by the early 1990s had effectively reduced the Kariba Weed cover to insignificant levels. Unfortunately, after the Kariba Weed was controlled, Water Hyacinth was able to spread rapidly, probably due to lack of competition with Kariba Weed. Water Hyacinth is now being controlled by the Neochetina weevils described

Box 7.3. Wetland Conservation: The Ramsar Convention and Lakes

One of the most important international initiatives to protect and restore wetlands is the Convention on Wetlands (Ramsar, Iran, 1971), known as the Ramsar Convention for short. The approximately half of lakes in this survey have Ramsar sites, which include, in some cases, both littoral areas and the lakes themselves.

The Ramsar Convention defines "wetlands" in its Article 1.1 as "...wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" and Article 2.1 provides that wetlands "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands".

For lake systems, a detailed Ramsar Classification System for Wetland Types the classification has the following categories:

O-Permanent freshwater lakes (over 8 ha); includes large oxbow lakes.

P-Seasonal/intermittent freshwater lakes (over 8 ha); includes floodplain lakes.

Q-Permanent saline/brackish/alkaline lakes.

R-Seasonal/intermittent saline/brackish/alkaline lakes and flats

Note that for the Convention lakes can be fresh, brackish saline or alkaline. Lakes in general are not well represented as wetlands of International Importance, although some regions have good representation. More importantly, the fact that the Convention urges contracting parties to manage effectively and sustainably all wetlands, including lakes, within a contracting parties national boundaries, means the Convention process and advice covers all lakes and the dependant biodiversity, even if some of this is migratory.

Of the Ramsar sites (wetlands of international importance) the areal extent of the 4 categories, in each of the Ramsar regions, is shown in the Table below:

	O	P	Q	R	all 4 types
Africa	14,535,913	16,253,389	1,593,452	2,294,209	24,313,987
Asia	2,904,800	1,589,078	4,100,218	2,442,435	6,118,175
Europe	15,372,268	5,807,754	3,818,388	2,172,043	16,861,747
North America	14,289,625	1,360,416	913,297	1,201,914	14,920,266
Oceania	704,720	3,609,323	477,211	1,789,330	4,982,808
Neotropics	18,751,932	11,116,523	4,391,158	8,242,720	25,440,355
World Total	66,559,258	39,736,483	15,293,724	18,142,651	92,637,338

The Ramsar Small grants fund, a rather small fund, has nonetheless funded lake projects to a value of around CHF 950,000, helping deal with management issues for lakes with a total areal extent of 4,278,364 Ha. The Lakes were in all regions of the world, including the following countries: Bulgaria, Former Yugoslavia, Armenia, Georgia, Russian federation (3), Algeria, Uganda, Burkina Faso, Comoros, Togo (2), China (3), Mongolia, Philippines, Argentina, Paraguay, Peru, Ecuador (2), and Bolivia.

The Convention will continue to promote wise management of lake systems, as part of its global approach to wetlands and water. Approaches that emphasize the need for integrated management approach, and build on the river basin initiative being developed between Ramsar, CBD and UNDP-GEF will continue to be advanced by the Ramsar secretariat. Lake issues will be included in the range of issues and advices to be considered by the next COP meeting, set for November 2005 in Kampala, Uganda.

Source: Peter Bridgewater, Secretary General, RAMSAR Convention.

above. The key lesson learned is that without attacking the root causes (high nutrient levels), control of one aquatic weed may just make room for another.

Fish can also be introduced to control aquatic weeds. For example, at Bhoj Wetland, herbivore Grass Carp (*Ctenopharyngodon idella*) along with Indian Major carp were introduced in the lakes to control submerged weeds such as Hydrilla, Najas and Vallisnaria. In order to avoid any problems cause by breeding of the Grass Carp, triploid species that do not reproduced were used. This introduction has resulted in the reduction of density of aquatic weeds up to 50% and increase in fish production by 130%. Thus there has been improvement of lake water quality as well as economic conditions of fishermen.

Biomanipulation

Biomanipulation is the deliberate introduction of species that will affect the lake's food chain in a beneficial way. The technique has been most widely used to control outbreaks of nuisance algae. In the classic approach, top-level predatory fish are introduced to a lake in order to reduce the populations of insectivorous fish. This, in turn, reduces the pressure on invertebrates which feed on the algae. Invertebrate populations increase and algal numbers decrease. While the technique has been successful in trials, it has not proven sustainable in the long-term. There are too many alternative food pathways and too many other influences on algae for the technique to be reliable. In addition, it requires a detailed knowledge of the aquatic ecology of the lake and the long-term presence of ecological monitoring. For these reasons, its use has been confined to lakes in the developed world and even there it is not in widespread use.

Chemical Measures

Biocides

Another possible technical response is to apply a chemical to a lake to control an algal bloom or to kill an invasive species. While bio-degradable chemicals can often be used to contain unwanted side-effects of a chemical, the cost is usually prohibitive is the infestation is extensive. For example, herbicides have been used at Lake Kariba to control both Water Hyacinth and Kariba Weed, but given the scale of the infestation, it was shown that chemical measures would be uneconomical. In addition, there is usually a strong public reaction against these methods, even when biodegradable chemicals are used. For this reason, this approach is not very common.

Physical Measures

Aeration

The decay of organic matter in a lake, either because of high organic loading from the watershed or from the decay of algal blooms, can lead to low dissolved oxygen (DO) in a lake. Low DO can lead to fish kills and the denial of benthic waters to commercially and ecologically important species. One short-term way of dealing with the problem is to inject more dissolved oxygen into the low DO area, usually the bottom of the lake. This is only viable in the smallest lakes. For example, aeration has only been used at the smallest lake in our study, the Bhoj Wetland, where a total of 15 aeration units have been installed to oxygenate the bottom water. This has not only caused improvement in water quality but has become a tourist attraction. Naturally, this effort does not attack the root cause of low DO levels which is high organic loading and eutrophication of the lake.

Freshwater Diversion into a Basin

In cases where water in a lake basin is in short supply or when a lake has been heavily polluted, another physical countermeasure is to bring more water in from outside the basin. Adding more water to a lake and/or its basin can alleviate a water shortage or it can serve to dilute already polluted water, thereby lowering the concentration of pollutants in the lake. While bringing in more water does not address the root causes of any problems (inefficient water use, overuse, or pollution), it is nevertheless used in some cases.

For example, to alleviate a chronic water shortage in the Lake Dianchi basin caused by rapid population growth in a water scarce area, a water transfer scheme from the Zhangjiuhe River (a tributary of the Jinsha River which is located downstream of the Dianchi Basin) is under construction (expected completion date of 2005/6). The project will bring in about 245 million m^3 of water into Kunming for the purpose of the city's water supply. Additionally, the Aral Sea brief notes that "during the latter part of the Soviet period, water managers in Moscow and in Central Asia proposed diversion of massive flow, up to 60 km^3, from Siberian rivers to the region as the panacea for perceived water shortage problems. Although real and serious potential ecological threats (of regional, not global magnitude as claimed by some opponents) were given as the chief reason for canceling the project, economic considerations were the fundamental factors in this decision." The Issyk-kul brief also mentions similar yet-to-be-implemented schemes to transfer water into the basin in order to maintain development of irrigation (in the Issyk-kul basin), and also to maintain the current water balance and water level of the lake.

A unique "diversion" scheme is currently taking place at the Aral Sea (apart from the proposal discussed above). Desiccation of the Aral Sea, due to diversions of inflowing rivers, has lead to the split-up of the lake into three parts (as of 2004). A small dike has been built between the Small Aral in the north and the Large Aral in the south. The dike is used to retain water in the smaller yet deeper northern part; without the dam, water would continue being lost from the Small Aral to the Large Aral, where it tends to be rapidly lost due to high evaporation. It is expected that the Large Aral will completely dry up in the mid-term, but with this "diversion", the Small Aral will stabilize and a portion of the biodiversity of the original Aral Sea will be maintained. Aladin2 provides a full report on this intervention.

A key lesson from these diversion schemes is that, while they may have a positive effect on the basin that receives that water, there is undoubtedly a negative effect in the basin that loses the water. There have been numerous diversions *from* lake basins (e.g. Aral, Baringo, Chad, Nakuru and Sevan), all with large, often unexpected, negative effects. Proposed schemes of water transfer from Lakes Naivasha and the North American Great Lakes have not been carried out, in part due to the knowledge of these negative experiences and economic reasons.

The use of transferred water to "dilute" a polluted lake is more common at small lakes than at the type of lakes in our survey. However, one of the purposes of the Lake Dianchi diversion discussed above is to change the flushing rate of the lake in order to decrease the hypereutrophic conditions that currently prevail. The Lake Ohrid case discusses how a large river (Sateska) was diverted from its natural course, which originally flowed to a point outside of the Lake Ohrid basin, to a new course within the basin that was designed to drain a marshland for farming and to increase the hydropower potential of the lake. The purpose was not to "dilute" the water of Lake Ohrid, which at the time was oligotrophic, but the effect of the diversion was to increase the size of the Lake Ohrid subwatershed by about 174%. The problem was that this new inflow brought with it a large load of sediment and organic matter that has had a negative effect on the lake.

Nevertheless, it is obvious that the proverb "dilution is not the solution to pollution" is perfectly correct. Given the integrating nature of lakes, even if a greater water volume is somehow attained, it is only a matter of time before the pollution spreads. In fact, the Lake Ohrid case shows that "dilution" can actually be a cause of "pollution". A key lesson from these diversion schemes is that, while they can have a positive effect on the basin that receives that water, there is usually a negative effect in the basin that loses the water and sometimes even in the lake receiving the additional water. Very thorough studies need to be carried out in advance to understand these likely consequences. Again it is a matter of balancing these benefits against the costs and taking into account the equity issues in any such water transfers.

Dredging

The removal of sediment from lake bottoms by hydraulic dredging is a common activity to removed excess silt, nutrients, and toxic compounds. For example, changes in basin land use led to large increases in sediment loading to both the Bhoj Wetland and Chilika Lagoon. For the Bhoj Wetland, the deposition of silt had created a land mass formation at confluence points which resulted in decrease in storage capacity and surface area, as well as the obstruction of the lake's outlet. Silt was removed from the upper and lower lakes by both hydraulic and dry excavation means, increasing the capacity of the lake by 4%. The excavated materials were used to convert previously barren lands into productive lands for agriculture. At the Chilika Lagoon, siltation of the outlet of the lake resulted in a decrease in salinity which caused both a decline in the native fisheries as well as an increase in invasive macrophytes growth. A new channel to the ocean was dredged and the salinity returned to normal conditions, leading to a dramatic recovery of the fishing and prawn industries. There was also a decrease of the area covered by invasive species and substantial increase in the weed free zone consequent upon desiltation operation. Pattnaik provides a full report on the work at Chilika.

Dredging of sediment is also sometimes used to remove internal sources of nutrients (usually phosphorus) in shallow, eutrophic lakes or toxic contaminants. For example, the Lake Biwa, Bhoj Wetland and Lake Dianchi cases all describe how dredging was carried out to remove phosphorus-laden sediment. In another example, 140,000 tons of PCB contaminated sludge were removed from the sediment of Cumberland Bay in Lake Champlain at a cost of US$35 million. Similar programs have been used to remove toxic contaminants from the North American Great Lakes and heavy metals from Lake Dianchi. However, the sediments of a lake are part of a complex ecosystem harboring benthic organisms that act as food for higher trophic levels and provide services such as removal of nitrogen. Removing sediment invariably destroys these functions.

The key lesson from these dredging activities is that, if the root cause of the problem (excess siltation, nutrient loading or toxic contamination) has been controlled, then dredging can have a positive effect on a lake. However, dredging, by itself, without load control is not cost effective and only a temporary measure and may destroy important ecosystem functions.

Harvesting

In many cases, excessive macrophyte growth impedes boat traffic, blocks irrigation channels, interferes with hydropower generation and water treatment plants as well as degrading recreation values. Infested areas can also foster the spread of vector-borne diseases. Harvesting these macrophytes can be a relatively quick and direct way to remove the nuisance weeds as well as the nutrients and any toxic chemicals they may have accumulated.

The Bhoj Wetland, Lake Biwa, Chilika Lagoon, Lake Toba and Lake Victoria briefs all discuss how harvesting has been carried out for a variety of reasons. Of special interest are the harvesting programs at Lakes Toba and Victoria which have relied heavily on community involvement. The harvested weeds can sometimes be turned into an economic good by local communities. In the case of Lake Victoria, the weeds were used for handicrafts. However, harvesting is usually a temporary measure that does not address the root causes leading to excessive macrophytes growth.

Key Lessons

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

- Technological interventions by themselves are not sufficient: root causes must be addressed.
- When diverting wastewater, don't forget about the "new" downstream.
- It is cheaper to prevent toxic contamination that to dredge a lake.
- Extensive research is needed to ensure that the introduction of a biological agent to a lake will not have unexpected effects.
- If root causes of macrophytes growth (high nutrient levels) are not addressed, successful removal of one species can just make way for another species to invade.
- Water diversion schemes, while they may have a positive effect on the receiving basin, can be disastrous for the exporting basin.
- If the root cause of a problem has been controlled, then dredging can have a positive, long-term effect.

Further Reading

1. Akashah examines the not only the technological measures to protect a small urban lake in Malaysia but also the construction of the lake itself and how it fits within the broader urban development framework.
2. Aladin2 provides background on the construction of a dike to prevent further salinization of the Northern Aral Sea (due interestingly to upstream water diversions for agriculture---another technical intervention).
3. Magadza considers how wastewater treatment was carried out to reverse the eutrophication of Lake Chivero, Zimbabwe, but how increased population as well as lack of operations and maintenance for the wastewater treatment led to "re-eutrophication" as well as pathogenic contamination. The Chivero case shows the absolute long-term need for vigilance in lake basin management.
4. Muhandiki covers the development of sewerage and sewage treatment systems at two cases in Africa (Lake Nakuru, Kenya) and Asia (Bhoj Wetland, India), noting the need, again, for good planning and through maintenance.
5. Pattnaik shows how a relatively simple engineering project (the dredging of a new channel to the sea) at the Chilika Lagoon, India, along with watershed-based measures such as public participation, greatly increased ecosystem health and income for fishers in the basin.
6. Watanabe discusses two diverse cases (in the USA and Japan) for controlling non-point effluents from rice fields through reuse and recycling of water. It shows that even problems commonly seen as "difficult" such as nonpoint source pollution can be effectively handled.