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Pollution Technologies for Conservation of Lakes

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ABSTRACT

Lakes are suffering from different stress factors and need to be restored using different approaches. The eutrophication remains as the main water quality management problem for inland waters: both lakes and reservoirs. The way to curb the degradation is to stop the nutrient sources and to accelerate the restoration with help of in-lake technologies. Especially lakes with a long retention time need (eco-) technological help to decrease the nutrient content in the free water.

The microbial and other organic matter from sewage and other autochthonous biomass causes oxygen depletion, which has many adverse effects. In less developed countries big reservoirs function as sewage treatment plants. Natural aeration solves problems only partly and many pollutants tend to accumulate in the sediments.

The acidification by acid rain and by pyrite oxidation has to be controlled by acid neutralizing technologies. Addition of alkaline chemicals is useful only for soft waters, and technologies for (microbial) alkalinization of very acidic hard water mining lakes are in development. The corrective measures differ from those in use for eutrophication control.

The contamination of lakes with hazardous substances from industry and agriculture require different restoration technologies, including subhydric isolation and storage, addition of nutrients for better self-purification or anaerobic technologies, to eliminate the pollutant nitrate by microbial denitrification. The retention time is an important parameter for modellers and limnologists that allows them to decide, which technologies – hydromechanical, chemical or biological – have to be applied alone or in combination to cope best with each specific problem. The technologies have to be economical and ecologically safe.

Keywords: lake degradation, lake restoration, restoration technologies, residence time, recovery

INTRODUCTION

Lakes, both natural and man-made suffer from urban, industrial, agricultural and other impacts. As a result, many aquatic ecosystems have become severely degraded and need to be restored. In many countries, large sums of money are now being spent to restore such lakes (Allan 1997). During the last three decades experience and expertise has increased worldwide. But the high investments, that are needed demand for a more scientific and sustainable ecosystem management, i.e. to restore the degraded lake to a level that can be permanently sustained through protection and conservation. The water-quality target should be in accordance with quality of natural waters, and without the stresses, that cause degradation, i.e. with a good ecosystem health, long-term stability and sustainability. Such conditions prevailed in the pre-industrial time. In the drainage basins of the lakes the organic matter production has now dramatically increased because of the intensive use of nutrients (N, P) by the agriculture in the lake catchments, industrialization and the population density. A good orientation about the pre-industrial status may be gained with help of paleolimnological investigations. Deeper layers contain fossils of more sensitive indicator organisms and the thickness of the yearly sediment layer is growing. The time needed to achieve the restoration target is longer than one would expect on basis of some existing models: it depends first of all on residence time (RT) and is included in most mode is applied (Imboden & Gaechter 1978).

Water quality management of lakes and reservoirs was first oriented to control eutrophication and the factors causing increase of nutrient load (Table 1). Many solutions are now available to control eutrophication by minimizing the nutrient inflows. But often organic loads, acidity, salinity or contamination with hazardous substances need to be controlled. The amendment of the conditions may be very different, in some cases contrary to the technologies developed to control eutrophication.

Table 1: Main Stress Factors, demanding restoration activities on and in lakes

Lake Ecosystem Stress	**Main Reasons**	**Consequences for Ecosystem**
Eutrophication	Nutrient load from point sources	Unwanted high plant growth algae blooms, fish kills (very numerous)
Saprobization & microbial infection	BOD from : Antropogenic sources (sewage) Natural sources (e.g. humic matter from rewetting of bogs) Autochthonous biomass	Oxygen depletion, fish kills.
Acidification	Acid rain with SO2 & NOx Geogenic sulfur acidification from pyrite oxidation	Low pH, metal load, absence of hydrogen carbonate, low species diversity (soft water lakes in the primary rocks, mining lakes)
Stalinization	Transpiration losses by irrigation Transpiration losses by big surface Connections of salt layers	Decrease size of lakes. Decrease of the through flow Meromixis in mining lakes
Contamination	Hazardous substances; industrial wastes, nitrate or pesticides from agriculture	Oxygen depletion, insufficient self purification.

Table 2: Control of the Nutrient export from the drainage basin and the nutrient import into lakes

Measures	Examples
Point Sources	
1. Diversion of sewage from the drainage basin. 2. Rational water use with recirculation and use of the secondary raw material. 3. 3. Sewage treatment with nutrient elimination or nutrient utilization	Ring sewage system and purification plants downstream the lakes are typical restoration approaches for many alpine lakes. Sugar factories with full recirculation do not produce wastes.
Non point sources	
4. Afforestation of erosion endangered steep slopes. 5. Establishment of protecting zones and adapted agricultural practice. 5.1 Soil utilization and hydromelioration with minimum nutrient losses. 5.2 Fruit sequences with intercropping, permanent vegetation cover 5.3 Fertizing according to plant demand (kind amount and time. 5.4 Soil treatment (ploughing, harrowing sowing…) parallel	Protecting zones with rules for performing land use with minimized nutrient losses are standard at drinking water reservoir and exemplary for all lakes.
Barriers for nutrient entry to lake	
6. Protecting forest belts along the inflowing rivers 7. Prebasins with crown overflow for nutrient elimination. 8. Extraction by macrophytes. 9. 9. Phosphorous elimination plant (PEP) at main inlet	The belt functions as a buffer system. Harvest without fertilizing curbs the output to the water bodies. About 50% of the incoming P does not reach the main reservoir. Inlet “bioplateaus” wetland with harvest. PEP are in operation at Wahnbach Reservoir, Tegeler See,Schlachtensee, Ulmener Maar, Susser See.

CONTROL OF EUTROPHICATION

Curbing the nutrient import into a lake

The prophylaxis against eutrophication includes the socio-political tools for water quality management. They make use of the legal options for protecting the water body from harmful impacts, using statutory regulations that the lakes and their catchment can be controlled on a long-term planned basis to prevent the need for more costly clean-up measures. Thus "prophylaxis" has the highest priority, followed by activities for maintenance of a healthy state in which the nutrients are detained to prevent their entering the water body (Table 2).

The point sources reduction of phosphorus has been achieved using high level of technologies.The oxygen produced by algal photosynthesis is used for degradation of organic pollutants. In addition to the use of treated water for irrigation, the groundwater is replenished by artificial enrichment. Hence, water re-use in such countries with limited water resources is quite usual. Nonpoint sources of nutrient inflow to lakes are mainly caused by farming in the drainage basins. Agricultural soils are fertilized, irrigated, drained, to increase the bioproduction, the lakes in the same basin have to be kept on a low level of productivity. Therefore, buffer ecosystems are useful between agricultural and water areas. The predams at nearly all new drinking water reservoirs in Germany have to be operated with several days retention time (RT). Therefore, with inlet barriers and underwater walls the inflowing water is mixed into the whole volume to get as near as possible to the theoretical RT. From the predams the water is diverted by crown overflows to the main reservoirs, to make use of the vertical concentration gradient (Benndorf & Pütz 1987). Similar effects may be gained with natural or mining lakes, situated in chains along a river system. Upstream lakes also act as "prebasins" for water bodies situated downstream. The efficiency of the elimination of particulate matter may be increased with help of sedimentation traps and macrophytic biofilters in outlet and inlet reaches of the different "links" of the chain. In addition the Phosphorus-content of a lake may be decreased by increasing exports to the outflow or by immobilization in the sediments (Fig. 1).

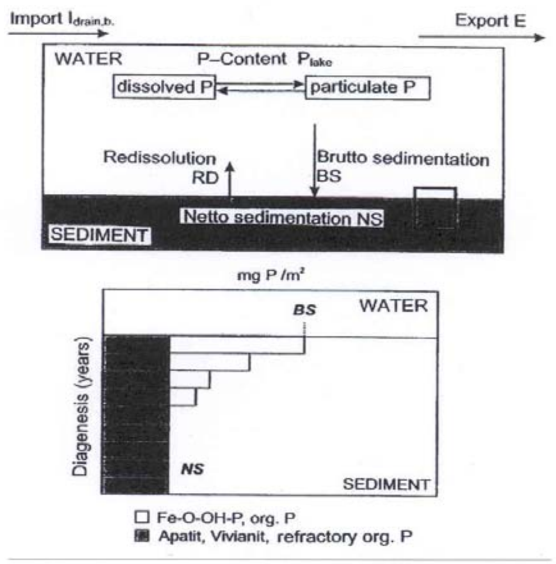

Figure 1. Outline of the phosphorus balance in a lake (modified from Hupfer & Scharf 2002)

Increasing the nutrient export

Using waters low in nutrient content a "dilution" of the Phosphorus-content in the lake may be achieved. The flushing sometimes improves the water quality even if total phosphorus in the flushing water is high (e.g. during high floods) due to the low utilizability of the Phosphorus compounds from erosion for algae growth. Also the settling of these particles and capping the sediments with silt may improve the water quality as could be demonstrated on small lakes .

In addition, in deep water bodies during thermal stratification the highest nutrient concentrations which are found in the deepest waters, can be reduced by using the bottom outlet to drain away this nutrient-rich water (Fig. 2).

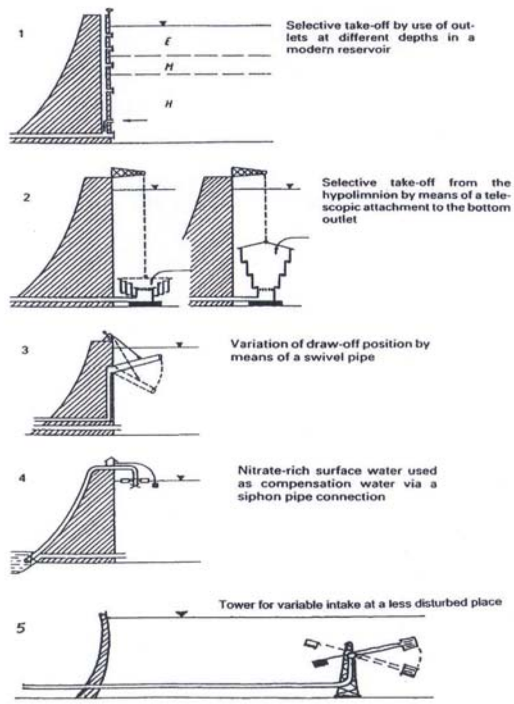

Figure 2. Water quality control in reservoirs by selective off-take (Klapper 1991).

In natural lakes the export of nutrients from deepest layers may be realized by means of the so-called Olszewski-tubes. The use of irrigation waters was licensed only for nutrient-rich hypolimnetic waters, extracted with flexible spiral wound plastic pipes (Klapper 1991). The technology was endangered, however, by high contents of H2S in relatively small hypolimnia and stinking irrigation water (Fig. 3).

New concepts now being implemented combining the deep water delivery with an on-site external Phosphorus (P) elimination. The treated water is fed back into the lake by pipe to the depth of the adequate temperature some what above the level of the intake. The so-called PELICON technology is a combination of precipitation, flocculation and flotation with compressed air. The continuous intake of P and its redissolution from the sediments not only improves water quality but also the P-binding capacity of the sediments (Keil 1995; Fitschen 2002).

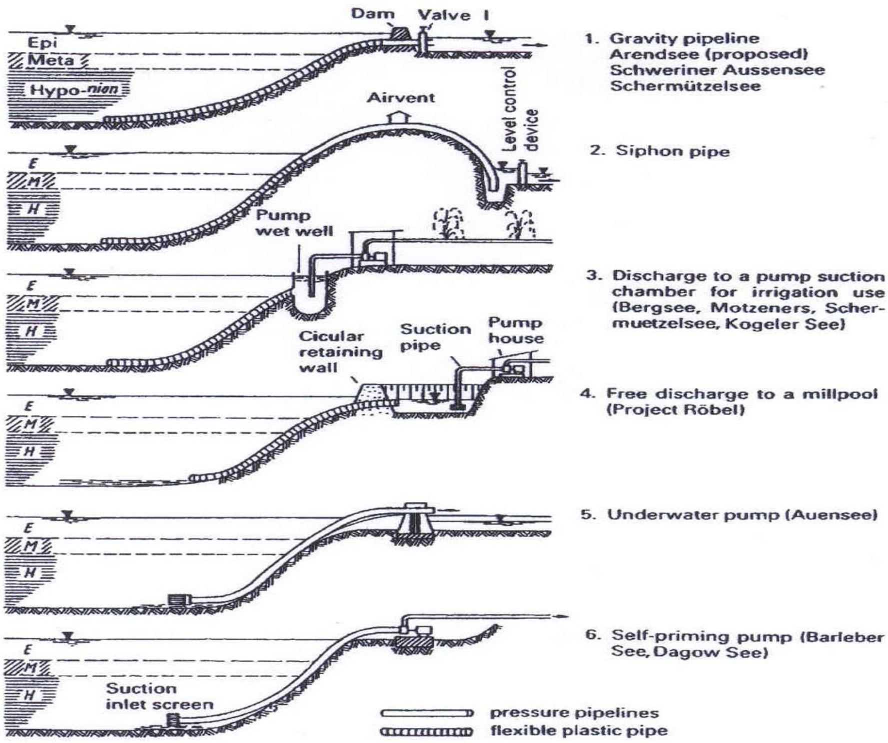

Figure3 Deep level abstraction; technological variants and typical cases in the former GDR (from Klapper 1991).

In June 2001 such a P-elimination plant was installed at the Kleiner Seddiner See with inlet TP concentrations of 80 to 100 µgl-1 and a backflow (target) of <20 µgl-1 TP. The treatment costs in the first year where 43 € m-3 (Vietinghoff 2001, 2002) (Fig. 4).

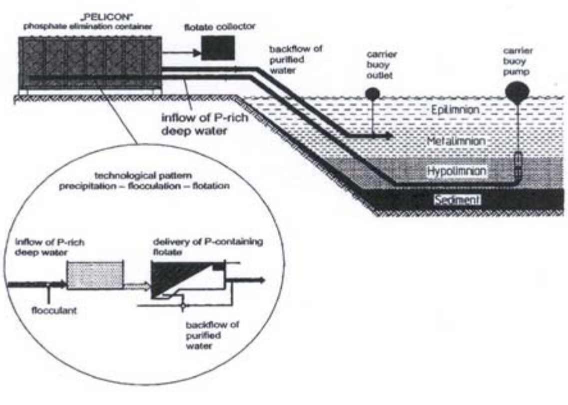

Figure 4. Transportable on-site phosphorus elimination plant "PELICON" (*sensu* Keil 1995).

Other P-elimination technologies use harvesting of phytoplankton: Algae-rich waters are skimmed with a special shovel from the surface of eutrophic waters and the algae with the nutrients incorporated are diverted mechanically by filters. An other option is a second filter step with P-adsorbing granules (Stelling 2002).For small lakes Richert (2002) designed a floating phosphorus elimination plant "NESSIE" on the basis of a filter with porous adsorbing granules with a large specific surface area of 300 m2 g-1. Lake water is pumped over the filter using a wind-solar hybrid system as the energy source (150 Wh). The P-loading capacity under laboratory conditions is about 60 g kg-1 adsorbent, but may be half as much *in situ*. The loaded adsorbent is suitable to be used as fertilizer.

In deep lakes a higher nutrient elimination during the stagnation period can be achieved using artificial mixing or destratification, so that deep waters with high nutrient contents are mixed with the epilimnetic waters, and exported with the outflow at the surface. In both, in deep and shallow lakes long-term scale the destratification increases the nutrient export, but short term effects differ. The most often applied method for destratification is the introduction of compressed air by boreholes in pipes inserted in horizontal position above the lake bottom. The air-water mixture with lowered specific weight causes a rising water curtain, destroying stratification and ideally the lake remains fully circulated the entire year. Other mixing technologies include pumping oxygen-oversaturated water from the surface down to the highest deficit near the sediment (MIXOX). The O2 - deficient water may be transported from the depth to the surface using rising pipes (aerohydraulic guns) or modified deep water aerators. The oxygenation of the deeper water takes place partly by the air-lifting, but mainly at the large surface of the lake. Further, under some specific local circumstances, where in a series of reservoirs or lakes, an oxygen-saturated lake is followed by a lake that is stratified and has an anoxic hypolimnion, the flow through pattern can be changed: the inlet to the stratified lake is dammed 0.5 ... 1.0 m by a weir and from this storage the inflowing waters are led with help of a pipe to the greatest depth of the hypolimnion. This very cheap "ecotechnology" combines oxygen import into the anoxic hypolimnion and mixing due to the higher temperature (Fig. 5 and Table 3).

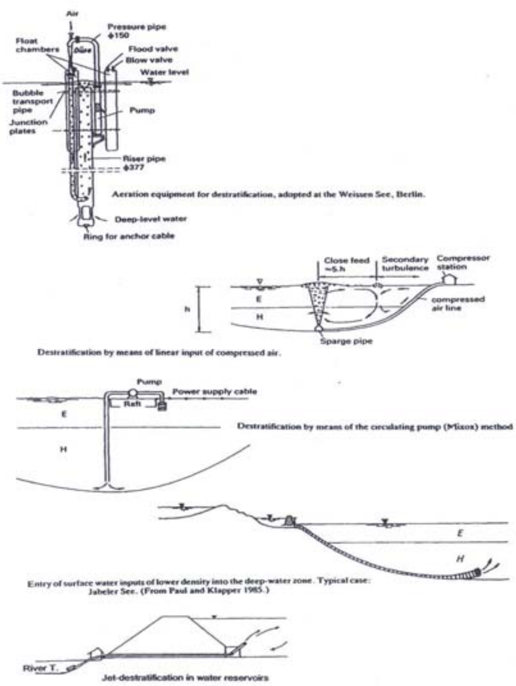

Figure 5. Destratification technologies.

Table 3. Increasing the nutrient export from a lake.

1. Flushing with nutrient-poor waters.
2. Deep water delivery.
3. On-site P-elimination by flocculation/flotation with water backflow.
4. On-site algae filtration by filters and P-adsorbers.
5. On-site algae skimming and separator thickening.
6. On-site floating P-elimination plant NESSIE with adsorbents.
7. Artificial mixing / Destratification (permanent or intermittent).
8. Harvest of fishes and macrophytes.
9. Sludge removal.

Fish harvesting influences the P budget only sporadically. Stocking of the lakes with fish sometimes introduces higher amounts of nutrients into the lake than the fishermen remove by their catches. But fishery may enhance the eutrophication by introduce certain fish and fish fodder. Bottom feeders like the carp intensify the redissolution of P from the sediments; the process is called as ichthyo-eutrophication (Rjabyshew 1972).

In shallow waterbodies dominated by macrophytes, removal and composting of the plants outsides may remove the biggest part of the Total Phosphorus. Harvesting should left over moderate stands of plants so as not to exchange macrophytes with phytoplankton, especially if the macrophytes are controlled using grass carps (*Ctenopharyngodon idella*). The lake can then become a weed free but plankton dominated, and very turbid lake. A better option is the mechanical harvesting of the submerged plants at only the bathing places thereby keeping the water of the main ecosystem clean.

Removal of sediments is an expensive method for removing the P, but it is the only possibility to counter rapid ageing and silting. After the sediment removal or de-sludging the lake is deeper, the volume and RT are higher and the oxygen demand and internal nutrient load are lower. De-sludging may be repayable if there is a demand of organic matter for soil improvement in the lake surroundings. The utilization of the lake sediments is an excellent example of a holistic landscape ecology: The organic matter and other fine particles such as the calcite crystals and plant nutrients originating from the sandy agricultural areas in the drainage basin and accumulated in the lake sediment, are brought back to the fields where they improve the fertility and especially the sorption capacity so that the nutrient losses from that areas will decrease in future. Some examples of the different technological measures for sludge removal are given in Figure 6.

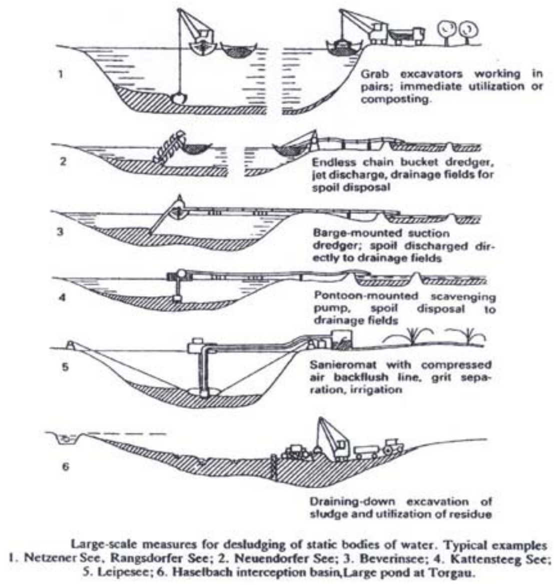

Figure 6. Large-scale measures for sludge removal from lakes or reservoirs (after Klapper 1991).

However sludge removal may be very expensive if the agricultural utilization is impossible due to hazardous pollutants in urban and industrial regions (mercury, pesticide metabolic, heavy metals...). In such cases the separation of the mostly non-polluted sand and mechanical drying and the very expensive special deposition of the contaminated fine-grained materials is necessary.

Increasing the P-sedimentation and preventing its re-dissolution

Phosphorus precipitation with iron or alumn salts is the most common method to decrease the phosphate contents in the free-water of lakes with long RT:

$M^3+ + 3H_2O = M(OH)^3 + 3H^+$

$M^{3+} + PO_4^{3+} = MPO_4$

The formation of hydroxides predominates in the competitive processes. The metal phosphate is either occluded within the flocs or deposited on the outside. During the formation of the hydroxide flocs, considerable quantities of H+ ions are released, which reduce the carbonate hardness, thereby reducing the buffering capacity:

$HCO_3- + H^+ = H_2O + CO_2$

In very soft waters with carbonate hardness below 10 mg l-1 CaO, the addition of only 3 mg/l Al3+ leads to a complete loss of the buffering capacity and further Al dosage would result in an ecologically unacceptable pH decrease. For P-precipitation in soft water lakes, the combination with neutralizing components like lime is useful (Panning, pers. comm.).

For applying iron salts as flocculants, the redissolution of the phosphates under anoxic conditions has to be considered. Therefore, the technology should include a sediment oxidation with nitrate and additional liming against acidification (Ripl 1978). A very long lasting P flocculation with liquid aluminum sulphate was performed in 1986 at Barleber See near Magdeburg (Roenicke *et al*. 1995). The water blooms with cyanobacteria have not returned in the 17 years thereafter and macrophytes again made the clear water stage to persist. The remarkable long-term effect was caused by the sediment capping with aluminum hydroxide/ aluminum posphate. Before the Al-flocculation each oxygen depletion in the small hypolimnion was followed by Pre dissolution. Until today the binding capacity of this layer holds back the P in the sediment even under anoxic conditions (Roenicke *et al*. 1995).

This explains why aluminum compounds are preferred to those of iron. Also easier handling of the less aggressive chemicals during the application contributes to the preference for Al. Today many different flocculants, as well as many flocculant aids like polyacrylamide, bentonite, clay powder etc. are available and for each case the dosage may be optimized (Table 4) Technological realizations are given in Figure 7.

Table 4. Increasing the phosphorus flux to the sediment and curbing the re-dissolution.

1. Phosphorus precipitation with iron salts ($FeCl_2$, $FeCl_3$, $FeSO_4$ ...) alone and combined with nitrate and $Ca(OH)_2$.
2. Phosphorus precipitation with aluminium salts (AlCl3, $Al_2(SO_4)_3$, $Al(OH)_2Cl$, $AlSO_4Cl$, Polyaluminiumchloride ...) alone and in combination with calcium carbonate.
3. Phosphorus precipitation with lime.
    - 3.1. Direct application of calcium carbonate or calcium oxide/hydroxide (CaO, $Ca(OH)^2$, $CaCO_3$, coccolithic lime).
    - 3.2. Flushing of natural calcite layers (Arendsee).
    - 3.3. Stimulation of calcite forming with addition of CaO and oxigen in the hypolimnion (Schmaler Lucin).
4. Sediment conditioning with oxidizing chemicals or aeration.
5. Sediment capping with sand (Hamilton harbour).
6. Sediment capping with clay from gravel excavation or clay powder (pilot experiments).
7. Collecting the youngest sediments in "sediment traps".

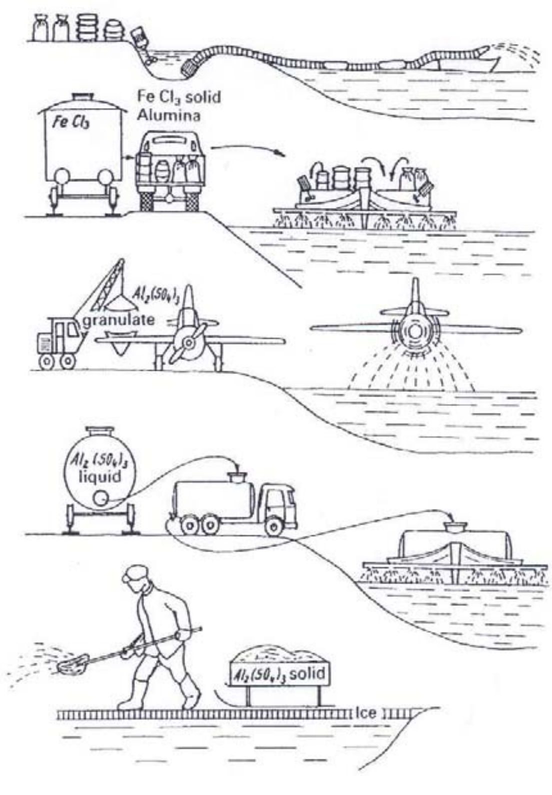

Figure 7. Large-scale measures for phosphate flocculation in natural water bodies – case studies.

Calcite may serve as an active barrier material and as sediment capping. The result of the P-binding of different technical products depends on particle size, specific surface-area and on the fine structure of the calcite applied. The coccolithic lime, formed several million years ago belongs to those with extremely large specific surface area and good sorption ability. A combined restoration approach with polyaluminium chloride and coccolithic lime was successful at Auensee in Leipzig, and 2002 the long-lasting dominance of the *Microcystis* was broken (Menschel, pers. comm.).

The idea to utilize natural littoral calcite layers for sediment capping resulted in relatively modest P-reductions in the free water. 57,000 m3 internal lake lime were flushed 1996 with help of a cutter-head suction dredger and spread on the bottom of the 5 km2 big lak

Sediment capping is another way for preventing Pre dissolution. In this respect, sand and clay minerals are currently being investigated (Zeman *et al*. 1997; Quandt 2001). Sediment capping with clay occurs as a side-effect during the underwater sand and gravel excavation. During the wet excavation the mining lakes become turbid from the clay resuspension. But, after the mining has terminated the fine particles settle and clear and P-poor water allows macrophytes to grow. Measures for supporting macrophytes such as lowered water table, controlling plant-feeding animals or introducing suitable macrophytes belong to restoration tools aimed at preventing algae-dominated turbid waters. Fresh sedimented plankton organisms with their high contents in organic matter, P and microbes contribute importantly to nutrient redissolution, and therefore need to be moved to excavated traps and Collected by "funnel effect".

Food-web manipulation

In addition to the diverse hydromechanical and chemical technologies many biological methods of eutrophication control are now available. These include changing the fish stock to a decrease in planktivores and a higher share of predator species. Thus the effect of prey fish on the zooplankton is reduced and the phytoplankton growth may be controlled by the filter feeders. The best solutions should combine reductions of nutrient loadings, repeated reductions of planktivorous and benthivorous fish stocks, and concurrent establishment of piscivorous stocks. Available evident suggests that removing of fish populations could provide the trigger needed for complete lake recovery. Lake recovery has been achieved this way especially in Denmark, in the Netherlands, Norway, Sweden, Great Britain and Germany (Benndorf 1980, 1987; van Donk *et al*. 1989;

Meijer *et al*. 1989; Harper 1992; Gulati & van Donk 2002). Biomanipulation studies stimulated limnological research on the interrelations in food webs in lakes. Some unexpected developments were caused by water fowl, snails, mussels, carnivorous zooplankton, filamentous algae, changing species of water plants, weather etc. Many questions have to be answered by limnologists also in future. On all constellations however, biomanipulation is more effective if nutrient loads are reduced (Moss 1999). Domination of the fish stock by planktivorous tench (*Tinca tinca*) and the benthivorous carp (*Cyprinus carpio*) appeared to perpetuate the poor water conditions. A substantial fish removal effort over one year achieved a 57% reduction in the fish stock which led to a 2.5-fold increase in transparency. A strong top down effect of fish on the large sized grazers was evident as density and the body size of *Daphnia pulex* increased significantly after the fish removal. Thus reductions in bleak predation pressure may allow for increases in cyclopoid, copepod abundance and thereby a net increase in predation pressure on herbivorous zooplankton.

Macrophytes are combattants for phytoplankton in the use of the limited nutrients and they provide niches for zooplankton and periphyton. To allow a better macrophyte growth, the water table may be lowered that light may penetrate to the bottom. They may be planted by hand as starting cultures to develop the wanted bank and outlet "bioplateaus" and as floating reed or raft bioplateaus (simultaneously suppressing floating algae blooms). On the other hand, too many macrophytes may be nuisance for other lake uses by humans. That is true especially with so-called neophytes and neozoons, introduced from foreign countries. Without their natural enemies such plants like *Eichhornia crassipes*, *Salvinia natans*, *Elodea canadensis*, *Myriopyllum spicatum* and others tended in their new environment to mass developments causing huge economic damages. Therefore many different technologies for a water quality management by food-web manipulation need a high standard of symptom diagnosis and ecosystem knowledge for appropriate decision-making.

CONTROL OF ORGANIC LOAD (SAPROBIZATION)

In the industrialized countries the sewage load is reduced with help of rational water uses and sewage treatment. Also the biological purified sewage contains nutrients and increases oxygen demand at least indirectly by eutrophication and degrading biomass. The sewage treatment plant could not reduce the huge oxygen demand. The post treatment was performed in the reservoir with 14 large deepwater aerators and for accidental loading peaks additional chemical oxygen was supplied by injecting several thousand tons nitrate per year into the treated sewage before it entered the reservoir.

A new remediation method which directly affects lakes is the re-wetting of former bogs and wetlands. If carried out too quickly (one or a few years), the outflow of the re-wetted areas will be rich with humic matter and contain high concentrations of total carbon and phosphorus due to the degrading terrestrial vegetation.

Problems with high organic loading of lakes and reservoirs are common in many developing countries, especially around the megacities with often insufficient sewage treatment facilities. Where the water bodies and their self-purification potential are used, rather than treatment plants, the first discernible effect is oxygen depletion, and consequently fish kills occur. Some tropical reservoirs exhibit high H2S production and the water at bottom outlet has to be aerated to protect fish-life in the river downstream (Klapper 1997). Most reservoirs, built for hydropower generation, can be artificially aerated, by adding oxygen via surface aerators, via destratification facilities or by hypolimnion aerators. The aeration of the activated sludge in sewage treatment plants would have been the more economic method for satisfying the oxygen demand.

CONTROL OF ACIDIFICATION IN LAKES

The acidification by acid rain and by pyrite oxidation has to be controlled using special neutralizing technologies. Addition of alkaline compounds is useful only in soft waters acidified by increase of SO2 and NOx from burning processes and from traffic emissions, which spread over long distances with the wind. The typical pH of rain acidified soft-water lakes is about 4.5 to 5.5, the scale of aluminum buffer. In thousands of cases the neutralization was achieved by adding CaCO3 powder with help of aircraft in Sweden, Norway, Canada and USA. The measures have led to the return of fish life and the neutralization measures are an example of success in lake restoration (summary in Olem 1991).

The geogenic acidification caused by pyrite-oxidation is far more complicated. The typical pH of geogenic acidified hard-water lakes is 2.0 to 3.5 buffered by high concentrations of iron. Here, the alkalinity demand for a chemical neutralization is one to three orders of magnitude higher than for neutralizing rain-acidified waters. Microbial reduction of the high sulphate- and iron contents leads finally to the formation of FeS2 the main cause of acidification. The conditions necessary for the sulphate reduction in a mining lake are contrary to those for eutrophication control. For sulphate reduction the environment has to be anoxic, carbon and phosphorus should be added to initiate the acidity-binding processes. Such conditions are found mainly in the sediments, but there are difficulties in including the liquids from the uppermost sediment layers in the water circulation and the matter exchange.

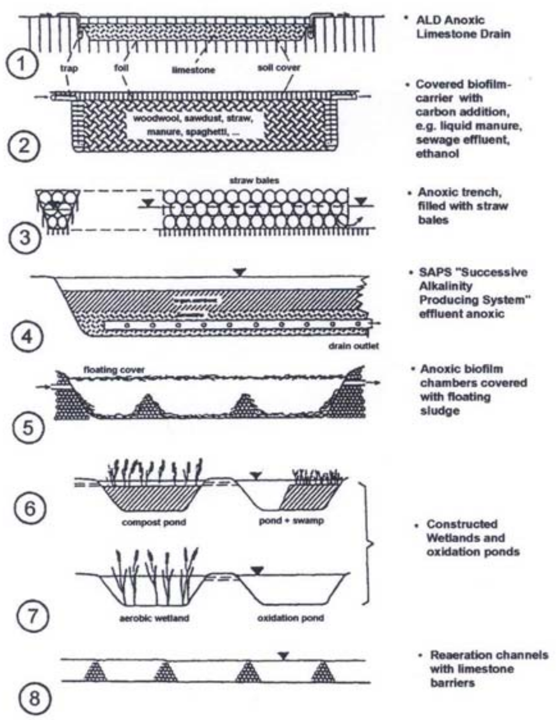

Figure 8. "Service ecosystems" for neutralization of acidic effluents (from Klapper & Schultze 1997).

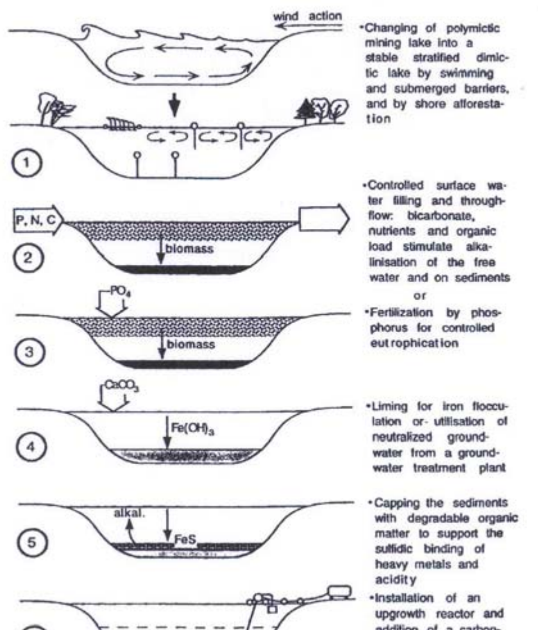

Figure 9. Abatement of acidification by *in situ*-technologies (from Klapper and Schultze 1997).

The abatement of geogenical acidification should be realized in all steps of the mining process: preparation, performance and recultivation of the landscape. Exposure of the pyrite containing minerals and other materials to the atmospheric oxygen has to be minimized. Layers with the highest pyrite levels should be buried in the deepest part of the mine. For filling the new forming lakes, surface water with high carbon hardness showed to buffer and neutralizes the acidity. Several neutralizing technologies are known for acidic effluents from mining areas (Fig. 8). The neutralization of large acidic lakes is still a unaccomplished solved problem. Some approaches are shown in Figure 9.

SALINIZATION

The Stalinization of inland waters has different reasons. Sometimes more water is extracted and used than available. Especially the irrigation of desert soils leads to losses by evaporation. Water shortage in L. Aral, in the Dead Sea, L. Tschad, L. Nasser and some lakes in the aridic part of the USA belong to the most severe environmental problems on a global scale. Changes in hydrologic regimes in the above mentioned areas have serious consequences for the water quality too. Water depth of Lake Sewan, Armenia, is reduced by 18 m due to very high extraction for hydropower generation. A 40% loss of the volume and 12% of the area has the same effect as eutrophication: hypolimnion oxygen deficit, diminished Secchi-disc visibility, and development of bluegreen blooms (Meschkova 1976).

The salt layers at the bottom of some (mining) lakes leads to increased stability of stratification, increase of oxygen deficit, and accumulation of hydrogen sulfide, methane and ammonium in the deepest part of the meromictic lakes. The monimolimnion represents an extremely long RT with all problems for restoration such waters. Destratification, the most widely used measure in lake restoration, is dangerous because of the byproducts of anaerobic degradation and their greater oxygen demand. Technologies such as oxygenation using nitrate or liquid oxygen are expensive alternatives.

RESTORING A LAKE CONTAMINATED WITH HAZARDOUS SUBSTANCES

Opencast mining pits have been used by mining companies and the coal processing industry for dumping overburden, ash, coal dust, wastes from smoulderies and tar. Such deposits to the mining lakes of eastern Germany led to a great number of environmental impacts. The restoration of these impaired lakes requires different rehabilitation approaches. Deposits and contaminations may be removed and treated or the contamination may be isolated on the shore or at the lake bottom. Technologies were developed for ex-situ or in-situ rehabilitation of the contamination (Table 5).

Table 5. Treatment of deposits and contaminations in and at mining lakes (from Klapper & Geller 2001).

<table>
<tr><td colspan="6">Treatment of deposits and contaminations in and at mining lakes</td></tr>
<tr><td></td><td colspan="2">Isolation of contamination</td><td colspan="3">Rehabilitation of the contamination</td></tr>
<tr><td>Away from Lake</td><td>Beneath the Lake</td><td>In the lake</td><td>Ex-situ technologies off-site/on-site</td><td>Separate parts of the lake</td><td>Direct parts of the lake</td></tr>
<tr><td>Relocating to other (special) dumps</td><td>Mechanical covering with foils of plastic or soil & vegetation</td><td>Subhydric deposits</td><td>Physical technologies Sedimentation, flotation, stripping, adsorption, incineration etc</td><td>Enloures, limnocorrals, submerged straw-reactor</td><td>Mixolimnion, monimolimn, hypolimnion, sediment</td></tr>
<tr><td>Screening and deposition of only the hazardous share</td><td>Horizontal separation by sheet piling or slot sealing</td><td>Profound region Capping with sand,ashes, waste rock etc</td><td rowspan="4">Chemical technologies Coagulation, dissolving ion exchange, oxidation aerobic biotechnologies: activated sludge (+P), trickling filter, disc aerator… anaerobic bio technologies anaerobic fixed bed reactor for desulfurication, combined anoxic/oxic technologies</td><td colspan="2">Incorporation in biomass, transport into the sediment, addition of limiting nutrients to stimulate the biodegradation</td></tr>
<tr><td>Drying incineration</td><td>Geohydraulic locking wells against groundwater influx</td><td rowspan="2">Capping by material from the pelagic zone: algae, iron-hydroxide, calcite littoral covering with soil, planting vegetation</td><td colspan="2">Stabilization of stratification for anaerobic treatment in the deep water, flocculation and transfer to sediment.</td></tr>
<tr><td>Utilsation as secondary raw material</td><td>Geohydraulic extraction well again deposit water effluent</td><td colspan="2">Neutralization with lime, change of solubility</td></tr>
<tr><td>Pumping away the liquid byproducts for treatment (e.g. tar)</td><td>Treatment of the water from the deposit like sewage, tighting of the deposit by thixotropic matter</td><td>Surface covering with biological deodorizing filter covering with floating reeds</td><td colspan="2">Curbing H_2S by Fe^{-1}, NO_3 or liquid oxygen aeration surface aeration deep water aeration destratification</td></tr>
</table>

CONCLUSIONS

On a global scale, the factors causing water quality degradation and thus the restorative measures differ. Eutrophication, saprobization and microbial load, acidification, salinization and siltation, as well as contamination with hazardous substances are typical ecosystem stresses. The deviations from "natural" or "normal" conditions in the lakes demand adequate management measures based on monitoring results and decision support systems (Schauser *et al*. 2002). First, the RT has the effect of a buffer on the water volume. But the retention of the matter in the hypolimnion of the stratified lakes extends the dilution and remediation time, especially in meromictic lakes where the Retention Time (RT) in the monimolimnion may be decades. The sediments with their accumulated matter have a similar delayed effect for rehabilitation. Therefore, the ecotechnologies for lake restoration begin with the control of flow through to bring the RT as close as possible to the theoretical value, the quotient of volume and flow through. At many (mining) lakes not yet connected to surface running waters, exchange with the groundwater is decisive of the RT. But it is not easy to distinguish groundwater inflow and outflow at different localities in such manmade lakes. Near the surface, the infiltration or exfiltration is highest due to the "filter cleaning" by wind and wave action. The deeper parts of the littoral are clogged by biofilms in the course of time. The bottom may be watertight where dead algae accumulate. A few metres further tailing piles may be free from sediments and groundwater enters without greater resistance. During the filling process the morphometric conditions are rapidly changing. Nevertheless, it is imperative to estimate RT as one of the main factors being deciding for success or failure of the restoration measures planned or performed.

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