Lake Constance – a model for integrated lake restoration with international cooperation

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Abstract Lake Constance is the second largest prealpine European lake. Its international catchment area lies in the territories of the four European countries Austria, Germany, Liechtenstein and Switzerland. Since the fifties, a significant degradation of its state was observed as a result of the pollutants of more than 1.2 million inhabitants in its catchment area. To counteract this negative development, international cooperation was realized in the International Commission for the Protection of Lake Constance (IGKB). Thereby the phosphorus concentration in the lake water, after a maximum value of 87 mg/m³ phosphorus in 1979, was reduced to 13 mg/m³ until 2001. To prevent the negative effects of unfavourable climatic conditions resulting in an incomplete vertical circulation, the concentration of phosphorus must be reduced to 10 mg/m³. Crucial points in future are to sustain the present successes in lake protection, to reduce existing loads as much as possible, to compensate for loads which are not avoidable and to avoid future loads. A sustainable use of the lake is ensured only by an intact lake ecosystem.

Keywords Cooperation; eutrophication; Lake Constance; phosphorus; restoration; shared management

Introduction The region of Lake Constance, situated in the center of Europe, serves as the environment and place of work for about 1.5 million inhabitants. The lake has a unique natural and cultural value which must be preserved. Lake Constance is one of the most important drinking water reservoirs in Central Europe supplying water for more than 4 million people. On the other hand, the lake and its region are intensively used for settlement, industry, agriculture, fishery, traffic, shipping and tourism. In view of the various loads caused by these activities in all bordering countries the lake can be protected only through international cooperation.

Lake Constance is the second largest prealpine European lake by area and by volume after Lake Geneva (Figure 1). It is divided in two parts: the larger and deeper “upper lake” and the shallow “lower lake”. The catchment area is about 11,500 km² and covers the territories of the European countries: Switzerland with the Principality of Liechtenstein (49.9%), Germany (28.4%), Austria (21.3%) and Italy (0.4%). More than 85% of the whole waterload comes from the alps by the three tributaries Alpenrhein, Bregenzerach and Dornbirnerach in the eastern part of the lake.

Lake Constance is a phosphorus limited, mesotrophic to oligotrophic hard water lake with calcite precipitation due to biogenically induced increase of the pH. Electrical conductivity of the water typically ranges between 260 and 300 µS/cm². Some morphometric data are given in Table 1.

In view of international law, Lake Constance is a curiosity. National frontiers only exist in the “Lower Lake”. In the “Upper Lake” only the area from the shoreline to 25 m water depth is national territory of the bordering countries. The remainder is considered as common property, a condominium. This fact plays an important role for cooperation in the protection of the lake.

Eutrophication and restoration of Lake Constance Lake Constance is said to be one of the best examined lakes. Here limnological research has
been done for more than 100 years. A crucial point in this field is the fundamental work of the Institute for Lakes Research (ISF) in Langenargen during the past eighty years. For thirty years the fundamental research of the Constance University has been remarkable. Based on these and other investigations the development of the lake is well known.

Symptoms of eutrophication

The following section refers to the “Upper Lake”. Eighty years ago this part of Lake Constance was considered as a typical oligotrophic lake. Since 1935 the first changes in phytoplankton and the oxygen budget were observed. In the 1950s the first critical changes of its state became visible (IGKB, 1961). At this time there were no remarkable chemical hints to a modified trophic state but the organisms had already reacted. The phytoplankton biomass increased strongly, some algal species disappeared and new ones appeared. The first algal mass developments were observed – clear signs of eutrophication. A similar increase was stated for zooplankton and fish. The concentration of algal pigments in the bottom sediments had risen 20-fold during the 1950s, corresponding to a rise of diatom frustules and biogenic calcite deposition.

Restoration with international cooperation – International Commission for the Protection of Lake Constance (IGKB)

Total phosphorus had increased from 6 mg/m$^3$ in 1950 to 10 mg/m$^3$ in 1957. Although this development seems negligible compared to later phosphorus concentrations, clear-sighted scientists and politicians apprehended a severe danger for the health of the lake. It was clear that this danger could only be banished with co-operation of all countries around the lake.

In order to preserve the lake ecosystem from further degradation the International Commission for the Protection of Lake Constance (IGKB)
Commission for the Protection of Lake Constance (IGKB) was founded in 1959 on the base of an international agreement by the bordering countries Austria (Vorarlberg), Baden-Wuerttemberg and Bavaria (Germany), and Switzerland (St. Gallen and Thurgau).

The main duties of the IGKB are:

- to observe the state of the lake
- to confirm the causes of its pollution
- to recommend co-ordinated preventive measures and
- to discuss planned utilisation of the lake.

The organization of the commission is presented in Figure 2. The commission is composed of high officials of the member governments as delegates. The chairmanship changes every 2 years to another government according to a rotating system. The commission usually meets once a year and the deputies decide measures by the principle of unanimity. The bordering countries are obliged to consider carefully the protection measures that are recommended by the commission and to realize them as best as possible according to their national laws.

An international scientific and technical permanent expert board with its working groups serves as official consultant to the commission. These experts have five to six meetings per year. They elaborate the research program and restoration measures, check the success of them and coordinate all activities. The results are summarized and published in so called “green reports” (annual investigation data of the lake monitoring, evaluation of the state of the lake) and “blue reports” (case studies and special topics).

An important aim of the IGKB since its establishment has been the purification of waste water around the lake and in the whole catchment area with uniform rules and common programmes, by two means:

- uniform “Guidelines for keeping clean Lake Constance” (IGKB, 1987) and
- common programmes for the construction of canalization and sewage plants.

Fortunately in the beginning of the 1960s phosphorus was recognized as the main factor responsible for eutrophication. Thus the first steps could be adjusted to optimal reduction of phosphorus loads entering the lake.

During the 1970s the phosphorus concentration of the lake water increased further, partly with annual progression rates of 15% (Figure 3). As a result, algal growth increased many times. In 1979 phosphorus reached its maximum value of 87 mg/m³.

During that time channel systems and efficient sewage plants with three purification stages (mechanical, biological and chemical purification) were built in the whole catchment area. Since 1983 the phosphorus concentration in the outflow of the big plants for more than 30,000 inhabitants has been limited to 0.3 mg/l P. This is reached for example by a fourth purification stage with flocculation and sand filtration. In this stage, several other...
harmful substances (e.g. halogenated organic substances) can be removed too. Almost 93% of the inhabitants are connected to these plants. Altogether about eight billion Marks were invested. From 1980 onwards the phosphorus increase could be stopped and its concentration decreased from 87 mg/m³ in 1979 to 13 mg/m³ in 2001 (Figure 3). So effective sewage treatment and the ban of phosphorus in detergents have thus been important steps towards a sustainable development of the lake.

Without the above mentioned efforts phosphorus concentration would have exceeded 130 Mg/M³ with the consequence of severe blooms of blue-green algae (nitrogen deficiency) and incalculable effects for the lake and its utilization, e.g. as a source of drinking water for over 4 million people.

Response of the lake to the decline of phosphorus concentration

Nevertheless the true scale by which to estimate the effect of restoration is not the lowering of phosphorus but the biological response of the lake, especially that of phyto- and zooplankton, the macrophytes in the shallow water near the shore and the benthic community on the bottom of the lake.

The phytoplankton composition has changed in its quality and its seasonal distribution since 1985 to a situation known from the time of a more oligotrophic lake. For some years the algal biomass shows a decreasing trend in its quantity (Figure 3). Today the amount of mean biomass is about 10 g/m², at 50% of the biomass before 1990 (more than 20 mg/m²).

The zooplankton has shown decreasing biomasses for a few years too.

The macrophytes along the shore are a very good indicator of the trophic state of the lake. They indicate a maximum trophic state in the 1970s and a considerable improvement of the state of the lake up to today (IGKB, 1998).

The benthic community show a considerable time-lag in its reaction to lowering of the trophic state. But for some years species indicating declining nutrient loads can be found in an increasing part of the lake.

The concentration of fecal bacteria, indicated by Escherichia coli and coliform bacteria, which showed a maximum of about 15 bacteria/100 ml (yearly mean value) in 1988, decreased to about 5/100 ml in 1999. In 2000 their concentration in the central lake was below the limit values for drinking water (1/100 ml) nearly all through the year (IGKB, 2000).

The oxygen concentration, especially the minimal concentration above the bottom, has shown, since the critical concentrations below 2 mg/l in the 1970s an important improvement of the situation in the deep water (Figure 4).

Therefore the success of the protection measures can be ascertained in many signs for a reversal of lake development towards a state typical for a lower nutrient level.

Further aspects of man made changes

The pollution of Lake Constance with xenobiotic compounds and other harmful substances can be described briefly as follows.

![Figure 3](http://iwaponline.com/wst/article-pdf/46/6-7/93/42666/93.pdf) Development of phosphorus concentration and algal biomass in Lake Constance.
The load of this very heterogeneous group is low to moderate. No acute risks for the ecosystem of the lake or human use can be seen. But many kinds of harmful substances can be found in very low concentrations, especially in the sediments. The effects of the many substances acting together are unpredictable today. Therefore a preventive reduction of supply, avoidance of these compounds or retention at the source are necessary.

Another kind of stress is the structural interference caused e.g. by buildings at the shoreline like walls and ports, shipping, promenades, walls, dredging, settling, manipulations at in- and outflow. Especially the building up of the shoreline (Figure 5) causes heavy damage, e.g. by erosion.

In Lake Constance over 50% of the shoreline has been built up in a few decades. More than half of the natural vegetation disappeared. The ecological consequences were, on the one hand, a deterioration of natural living conditions, that is breeding grounds, wintering places for migratory birds and spawning grounds for fish. On the other hand there were the physical consequences, especially hydrodynamic processes with regard to waves and currents, which are as disastrous as the ecological ones. The balance between waves and currents on the one side and the sensitive vegetation and the conditions of sedimentation on the other side was disturbed. The waves could no longer slow down on a flat shore. They were reflected, and as a consequence of this the shoreline and the shallow water zone have been eroded, assuming horrendous proportions. In the last 40 years high cliffs arose around the lake. Together with the accelerated currents, the waves have important effects on erosion, siltation and particle-size distribution.

Therefore on the base of an ecological and limnological inventory and an assessment (stock-taking) of the shallow water zone, the so-called Lake Constance shore plan was drawn up in 1984. It comprises limnological protectorates and zones for restoration and rehabilitation including all public facilities. Its most important function is to regulate all planning along the German part of Lake Constance. Technical interferences on the shoreline is handled restrictively. Inside the limnological protectorates any technical structures and buildings are prohibited.

According to this plan, several restoration measures have been carried out to rehabilitate eroded or damaged natural shorelines as well as built-up shores. For this purpose a restoration model was developed by the Institute of Lakes Research. In the last 20 years the shoreline and the littoral zone have been restored in over 80 areas with a total length of 26 km, and their viability have been regained. Nowadays the management has become international. In Austria and Switzerland study groups have been founded and a lot of measures have been carried out or are planned.

**Future aspects**

Different models for the estimation of a tolerable P-threshold value agree in the fact that a further lowering of the P-concentration to a level of about 10 mg/m³ or below is necessary.
to recover good conditions. To attain this goal it is necessary to use all possibilities for further reduction of the phosphorus load coming from sewage and agriculture.

With increasing numbers of inhabitants the problem of growth of the remaining phosphorus and other harmful substances becomes topical. Therefore the IGKB “Guidelines” from 1987 demand a holistic view including the catchment area and all fields affecting the lake, especially in industry, agriculture, settlement and traffic. In addition to the stress caused by substantial loads the stress by structural interferences is to be considered in the same way. Preventive measures should be realised before harmful effects occur.

All these efforts may serve to develop Lake Constance to a state which is stable against anthropogenic stress interfering with unfavourable climatic conditions, which have increased during the last few years. To obtain this state it is necessary to improve the quality of the whole lake with its pelagic, littoral and profundal zones. At the moment Lake Constance can be described as an ecosystem in transition.

To sum up, the future goals of IGKB for protecting the Lake Constance are to obtain:

- a stable limnological situation for the lake
- an intact shore and stable ecological situation in the transition zone from land to water
- an adapted, sustainable use of the lake and its catchment area
- a permanent consideration of the environmental goals by everyone at any time during all actions and measures.

To develop the lake into an intact ecosystem and preserve it permanently, it is necessary to:

- reduce existing loads
- compensate for unavoidable existing loads
- avoid new loads
- carry out prevention before repair

Only an intact ecosystem can maintain a sustainable use of the lake for production of drinking water, fisheries and recreation.

References


