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The history of eutrophication and restoration of Lake Geneva

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This case study can be used in conjunction with *Module II Nutrient dynamics and eutrophication in rivers, lakes and coastal marine systems* of the NEAR curriculum. It illustrates the development of eutrophication in a large, deep lake, together with the impacts on the lake ecosystem. The factors influencing the onset of eutrophication are examined and the impacts of some remediation measures are described.

1 Introduction

Lake Geneva (Léman) (Slide 2) is the largest freshwater body of Western Europe, which has experienced man-induced eutrophication like many other lakes in the world. In the middle of the 20th century, fishermen observed unusual algal blooms and warned the sanitary authorities and scientific community about the "negative impact for men of the sewage and wastewaters which are continuously dumped in the Rhone river watershed". The present case study describes the history of eutrophication of this freshwater lake, the effects of active measures undertaken to reduce nutrient loads, and the chemical and biological recovery stages observed after this reduction.

Most data have been obtained through lake monitoring, initiated in 1957 by a group of scientists and continued by an International Commission between France and Switzerland (CIPEL: Commission Internationale pour la Protection des Eaux du Léman contre la pollution). The main aims of this Commission are i) to conduct scientific studies of the lake and of its watershed, and ii) to formulate recommendations to the government and to propose new legislation concerning the protection of this water resource.

The recognized uses of the lake, for which the water quality has to be maintained or improved, are:

- A source of drinking water for a population of about 500,000 (up to 100×10^6 m^3 a^{-1}). The quality of the lake water should permit its use after simple treatment only.

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Table 1 Main natural characteristics of Lake Geneva and its watershed

Lake location			
Geographical mean co-ordinates	46°27' N	6°32' E	
Mean altitude (m a.s.l)	372		
Watershed			
Surface area (km^2)	7984		
Mean altitude (m a.s.l.)	1670		
Maximum altitude (m a.s.l.)	4634		
Glaciated area (%)	9.4		
Lake morphology	**Whole Lake**	**Grand-lac**	**Petit-lac**
Surface area (km^2)	580.1	498.9	81.2
Volume (km^3)	89	86	3
Maximum depth (m)	309.7	309.7	76
Mean depth (m)	152.7	172	41
Axial length (km)	72.3	49	23.3
Water dynamics			
Mean discharge of the Rhone at Geneva (effluent) ($m^3 s^{-1}$)	252 (max: 327; min 166)		
Theoretical water residence time (years)	11.4		

- A major tourist attraction for sailing, boating, bathing and angling. The lake should be attractive, microbiologically safe, without algal blooms and unpleasant odours.
- The ecological quality of the lake environment should allow the presence and the natural reproduction of game fish such as trout and artic char.

2 Lake Geneva and its watershed characteristics

Lake Geneva is a deep, peri-alpine lake shared between Switzerland and France, filling a depression originating from glacial erosion of tertiary formations. The principal characteristics of the lake and its watershed are summarized in Table 1 (Slides 4 and 5).

The lake comprises two basins (Slide 3): the “Grand-lac” (volume: 86 km^3) to the East, and the “Petit-lac” (volume: 3 km^3) to the West. The maximum depth is 309.7 m, located in the centre of the Grand-lac. The mean annual discharge of the lake outflow at Geneva is 252 $m^3 s^{-1}$. The main tributary is the Rhone River (about 75 per cent of the total water input) entering the lake at its eastern end and exiting at Geneva. The other tributaries are the Dranse River on the southern shore (10 per cent) and the small rivers on the northern shore (5 per cent). Direct precipitation to the lake surface accounts for the remaining 10 per cent of the inputs. Considering the total volume of lake, the mean residence time of the water is 11.4 years. However, a study of the lake water dynamics using tritium tracer shows that water residence time in the surface layers is about 5 years whereas in the deepest part it reaches 20 years (Hubert, 1972).

Lake Geneva is classified as a warm monomictic lake (Lewis, 1983), with overturn taking place at the end of the winter season. However, its great depth and the climatic conditions

Table 2 Population and wastewater treatment plants in the Lake Geneva catchment (WWTP)

Permanent population (2003)	948’530
Tourist capacity (2003)	618’620
Number of WWTP (2003)	166
Total capacity of the WWTP (inhabitant-equivalent)	2’625’255
Percentage of permanent population connected to a WWTP (%)	90
Percentage of tourist population connected to a WWTP (%)	89

make a complete overturn relatively difficult. During the last half of the 20th century, complete mixing did not take place for long periods of time (see below).

The hypsographic curve of the lake volume is quasi linear, which indicates a pseudo-conical morphology of the lake. Only 7.6 per cent of the total surface area of the lake is shallower than 12 m. Therefore organisms developing in the pelagic zone (phytoplankton) dominate the biochemical processes compared with organisms (macrophytes) of the littoral zone.

The surface area of the watershed is 7,984 km^2 (including the lake surface area of 580 km^2). Land use in the watershed comprises uncultivated areas (34.5 per cent, glacier, rocks, and built areas), forests (22 per cent), meadows (23 per cent), and cultivated land (20.5 per cent).

The present population of the watershed (Table 2) is about 1.56×10^6 inhabitants, of which about 40 per cent are tourists. Ninety per cent of the population is connected to one of the 166 wastewater treatment plants (WWTP) built in the watershed.

3 The eutrophication history

The history of eutrophication in Lake Geneva can be divided into three periods corresponding to 1) the initial situation and early warning (before 1960); 2) the degradation period (1960–1980); 3) the restoration period (1980 – present). These periods are mainly defined by the trends of the yearly averaged phosphorus concentration in the lake water. Trends in the driving variables of eutrophication (i.e. nutrients) and the effects on the lake biology are described below for these three periods.

3.1 The early warning period (before 1960)

A comprehensive description of the lake at the end of 19th century was given by Forel (1892, 1896, 1904) in his monumental three-volume monograph *Le Léman*. The negative impacts of wastewaters discharged to the surface water, and the deterioration of the lake water quality that occurred after an unusual phytoplankton bloom in Lake Geneva, were first reported by local fishermen in 1950.

Before regular monitoring began, occasional studies of the lake included phytoplankton, benthic fauna, bacteria, macrophytes, water chemistry, geology and sedimentology (see Lang *et al*., 1984 for a comprehensive review). These works helped to evaluate the lake status. Regular monitoring of the lake started in 1957, and after four years of study, many indicators showed a degradation of the lake water quality, including:

- Modification of the annual cycle of lake water transparency (Secchi depth). From a simple cycle with a maximum in winter and a minimum in summer, seasonal variation in transparency changed to a double cycle with two minima, one in spring and the other in summer, separated by the "clear water" phase (Slide 13). This phase resulted mainly from the grazing activity of large filter-feeding zooplankton. The onset of the clear water phase is usually interpreted as an indicator of meso- to eutrophic status.
- Decrease in the dissolved oxygen (DO) concentration in the deepest water layers. The main source of DO at depth is water mixing during overturn, occurring usually at the end of the winter season. However, due to its great depth, Lake Geneva is characterized by incomplete mixing during mild winters, leading to extended periods of stagnation of bottom water. Minor sources of DO include turbulent diffusion from overlying water, and deep intrusions of river waters rich in DO. Before the degradation period, these minor sources were probably sufficient to compensate for DO used by micro-organisms to oxidize the low flux of settling organic matter.
- Increases of total phosphorus concentrations, especially in the deep water layers;
- Increase in the number of faecal bacteria in shoreline areas.

These observations led to the formal creation of CIPEL in 1962 between France and Switzerland. All Lake Geneva tributaries were included in the monitoring programme. During the following years, the trophic status of Lake Geneva continued to deteriorate rapidly.

3.2 The degradation period (1960–1980)

3.2.1 Chemical variables and indicators

Trends in phosphorus concentrations showed a dramatic, although somehow irregular, increase during the period 1960–1980 (Fig. 1, Slide 6). Before 1960, total phosphorus concentrations ranged between 10 and 12 $\mu g\ l^{-1}$, whereas they reached about 90 $\mu g\ l^{-1}$ between 1976 and 1979. This increase resulted from the release of untreated (i.e. without phosphorus removal) wastewaters into rivers and the lake, and the significant use of phosphate in detergents. For example, consumption of tripolyphosphates tripled in France in the 1960s (Rapin *et al.*, 1995). The spectacular fluctuations in phosphorus concentrations between 1962 and 1970, with a maximum increase in concentrations by a factor of two in one year, remain unexplained.

Nitrogen, particularly in the form of nitrate, is also a limiting nutrient at the N : P ratio < 7:1 (16:1 by atom). In the late 1950s, the mean nitrate (expressed as mass of N) concentration was below 300 $\mu g\ l^{-1}$ and steadily increased to 598 $\mu g\ l^{-1}$ in 1989 (Slide 7). The concentration of N showed a maximum two-fold increase, compared with an increase in phosphorus by a factor of nine in 16 years (1960–1976). During the period of the maximum phosphorus concentration in the lake (1976–1979) the N:P ratio by mass, as $N\text{-}NO_3$ and $P\text{-}PO_4$, respectively, was just

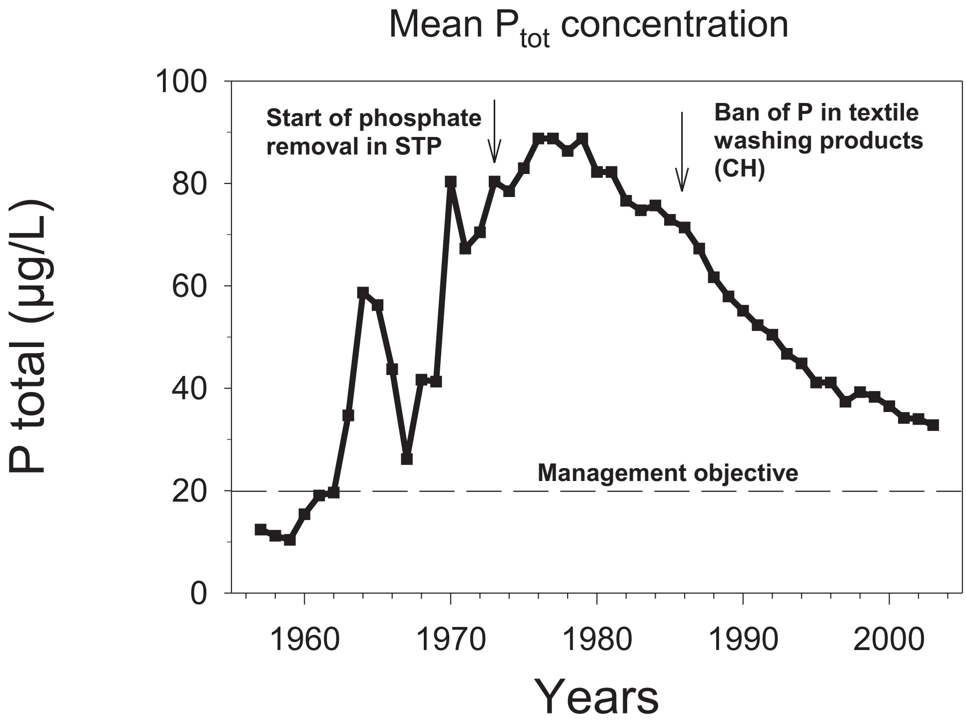

Figure 1 Evolution of the total phosphorus concentration in Lake Geneva.

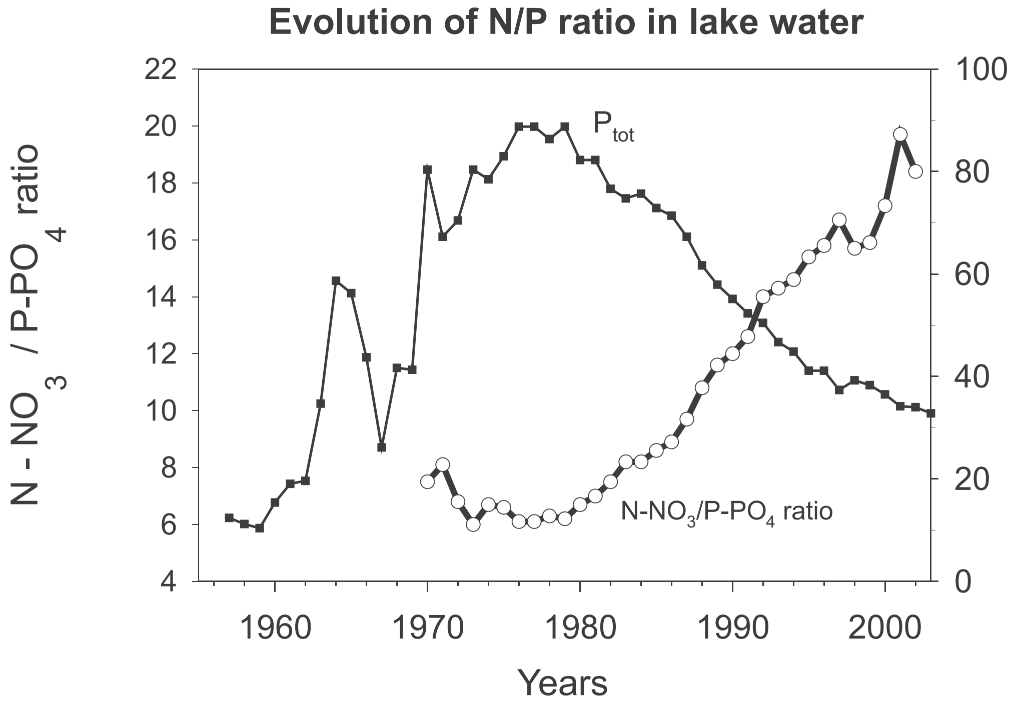

Figure 2 Evolution of the N/P ratio in Lake Geneva. The ratio is lower than 7 between 1972 and 1981. For comparison, the evolution of total phosphorous concentration in lake water is also shown.

below 7, whereas with phosphate decreasing and nitrate increasing, the ratio has been steadily increasing, reaching about 18 at present (Fig. 2, Slide 8).

Dissolved oxygen in the deepest water layer has shown a pronounced decrease in concentration during this period (Fig. 3, Slide 9). Between 1957 and 1979, complete overturns

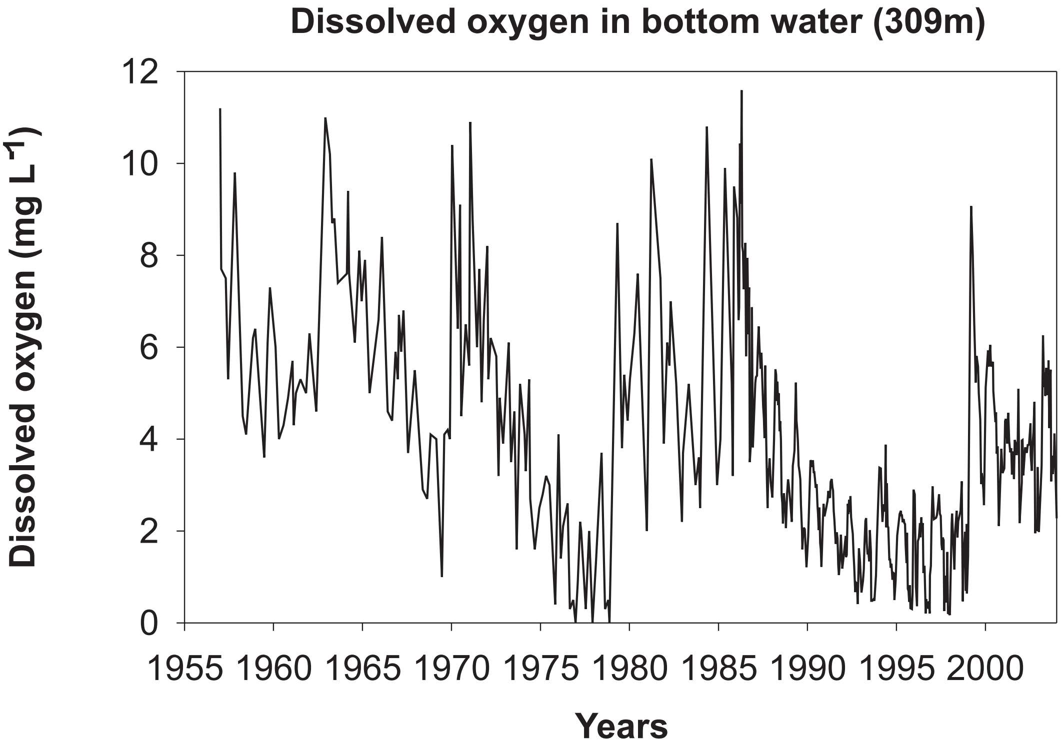

Figure 3 Evolution of dissolved oxygen concentrations in the bottom waters of Lake Geneva.

occurred in 1957, 1958, 1963, 1971 and 1972. During the same period the DO concentrations decreased with an accelerating rate, to less than 2 mg l^{-1} with episodes of anoxia in 1977 and 1978. A partial overturn in 1979 improved the situation with a DO concentration of 9 mg l^{-1}. The low DO concentrations enhanced the release of phosphorus from the sediments. The sediments became an "internal source" of phosphorus due to reduction of iron and manganese oxides, and consecutive release of phosphorus adsorbed onto these compounds. However, as only a small fraction of the near-bottom water become anoxic for a short time, the contribution of sediments as source of phosphorus to the lake water was of secondary importance.

3.2.2 Biological response to increased nutrient concentrations

In the early studies and up until 1974, phytoplankton samples were collected with a net. Therefore only the large, mainly colonial forms of phytoplankton were collected and identified. Before 1962, diatom species were dominant, with typical oligotrophic species (Slide 20) such as *Cyclotella* spp. and *Tabellaria fenestrata* (Balvay *et al*., 1984). The period between 1963 and 1966 seems to be the beginning of major changes in the phytoplankton community. Zygophycea, and especially *Mougeotia gracillima* showed a massive increase in numbers, and suddenly their numbers exceeded those of Chrysophycea species. In 1967 the proportion of diatoms was reduced to less than 50 per cent of phytoplankton biomass, and Cyanobacteria (*Planktothrix rubescens*), an indicator of severe eutrophication, showed massive increases (Slide 21). From 1968 to 1980, in addition to diatoms, the phytoplankton community comprised Dinophycea (*Ceratium hirundinella*), Zygophycea (*Mougeotia gracillima)* Cyanobacteria

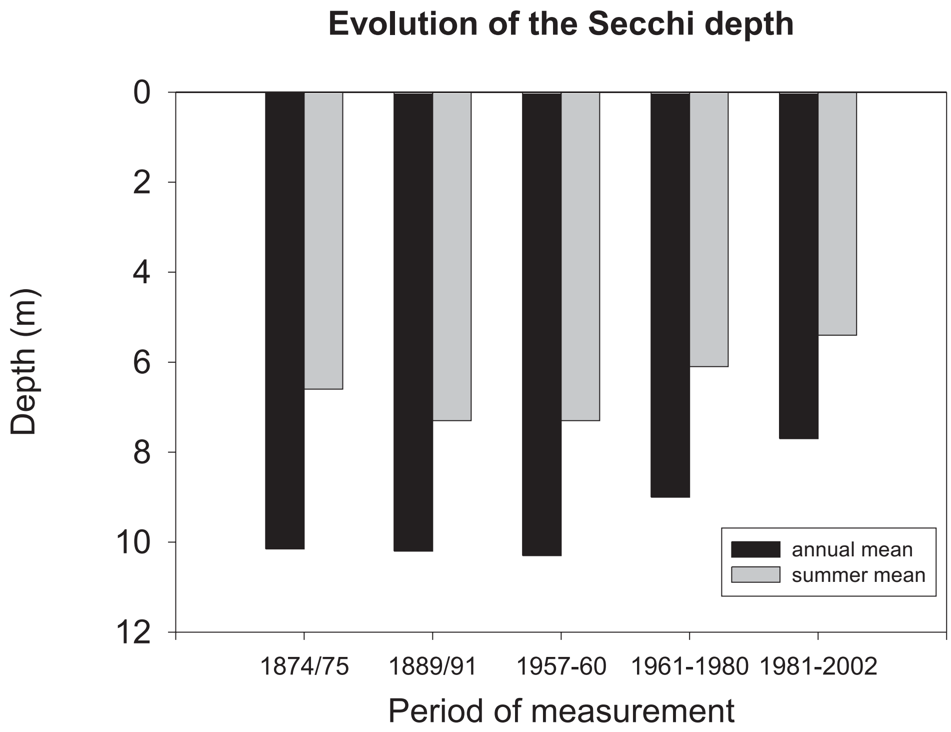

Figure 4 Comparison of the Secchi depth before, during and "after" the eutrophication period.

(*P. rubescens, Oscillatoria bourrellyi, Aphanizomenon flos aqua*). Chlorophycea, Chrysophycea and Xanthophycea occured only in small numbers.

The volume of phytoplankton varies from year to year. However, the maximum volume of phytoplankton observed before 1965 was about 3 ml m^{-3}, whereas in the 1970s it increased to above 5 ml m^{-3}. There were no systematic measurements of the phytoplankton biomass or productivity before 1974. However transparency, estimated by the Secchi depth, can be used as a surrogate of biomass. Trends in Secchi depth (Fig. 4, Slides 12 and 13) showed no variation between measurements performed by Forel (1892) at the end of the 19^{th} century and those obtained by CIPEL between 1957 and 1960. An overall decrease is recorded between 1961 and 1978, both for the annual and summer averages, indicating an increase in the algal biomass. This additional biomass, after settling to the lake bottom and decaying, is responsible for the decrease of DO concentration in the deep water.

Zooplankton has also been affected by eutrophication, more in terms of increased biomass than in term of community changes. However, some species such as the Rotifera *Notholca caudata* (oligotrophic) or *N. foliaca* (oligo-mesotrophic) have diminished, whereas *Keratella tecta* (meso-eutrophic) have increased (Balvay, 1999). Changes in zooplankton biomass closely follow changes in phosphorus concentration (Slide 15). This relationship reveals, at least for the eutrophication period, the close links where phosphorus enables the phytoplankton production, which in turn is the primary food for the zooplankton. Inter-annual variability of zooplankton biovolume is relatively large, but a marked increase is observed from 1957 to 1970 from about 100 to 200 ml m^{-2}.

Macrophyte communities (Slide 23) also experienced modifications as a result of eutrophication, directly due to the increase of available nutrients, and indirectly from a reduction in transparency due to turbidity increases or higher organic matter content in the substratum (Rapin *et al*., 1995). However, other causes are also responsible for the observed changes, particularly reduction or destruction of shoreline biotopes (less than 20 per cent of the Swiss shoreline is natural), or lake level regulation. The species diversity dramatically decreased, with only 43 species observed in 1973, compared with 83 at the beginning of the 20^{th} century. Moreover, the reduction in species number was higher for emergent species, with an absence of 19 species out of 28, as well as for Characea (9 out of 14). In contrast, submerged species increased in density and surface area. *Potamogeton pectanitus* became ubiquitous, whereas it had previously been considered as not abundant. In parallel, a reduction, from 8–12 m to 6–7 m, of the maximum depth at which macrophytes developed was also observed, probably due to a decrease in water transparency and the related decrease in light availability.

Fish populations in Lake Geneva are composed of Salmonidae (trout *Salmo trutta*, arctic char *Salvinus alpinus*, Coregonidae – powan, *Coregonus* sp.), Cyprinidae (mainly roach *Rutilus rutilus*), one Percidae (perch *Perca fluviatilis*) and one Esocidae (pike *Esox lucius*) (Slide 24). Eutrophication affected recruitment of some species, mainly Salmonidae, for which eggs are sensitive to dissolved oxygen concentration and sedimentation rates. Fishing statistics of the arctic char are inversely correlated with phosphorus concentrations (Slide 16). By contrast, catches of perch increased drastically between 1950 and 1980, due to increased fishing pressure, together with the abundant available food for this planktivorous fish.

Benthic fauna also experienced changes following lake eutrophication and these can also be used as an indicator of trophic status. Species which characterize oligotrophic lakes, with elevated DO and low organic matter content in the sediment, have been replaced by species which are less sensitive to low DO content and which proliferate because of the abundance of accumulating organic matter. Modification of the benthic fauna took place first in the deep parts of the lake where oxygen depletion first occurred. Between 1970 and 1980 the four Chironomid genders and the molluscs *Lymnaea* and *Pisidium* disappeared (Slide 22), as well as the "oligotrophic" worms. Only "eutrophic" species (*Tubifex tubifex* and *Potamothrix hammoniensis*) remained in the sediments below 290 m depth (Rapin *et al*., 1995).

3.2.3 Remediation measures

After the first observations of water quality degradation, political authorities implemented remediation measures to reduce the anthropogenic impacts on the surface waters. The construction of wastewater treatment plants (WWTP) started in the 1960s in the watershed. Major progress in improving the water quality of Lake Geneva was made at that time by the commissioning of the Lausanne WTTP in 1964. However, it was between 1972 and 1980 that the main effort was made with an increase in capacity from 0.5×10^6 to 2×10^6 population-equivalents for the whole watershed (Fig. 5, Slides 18 and 19).

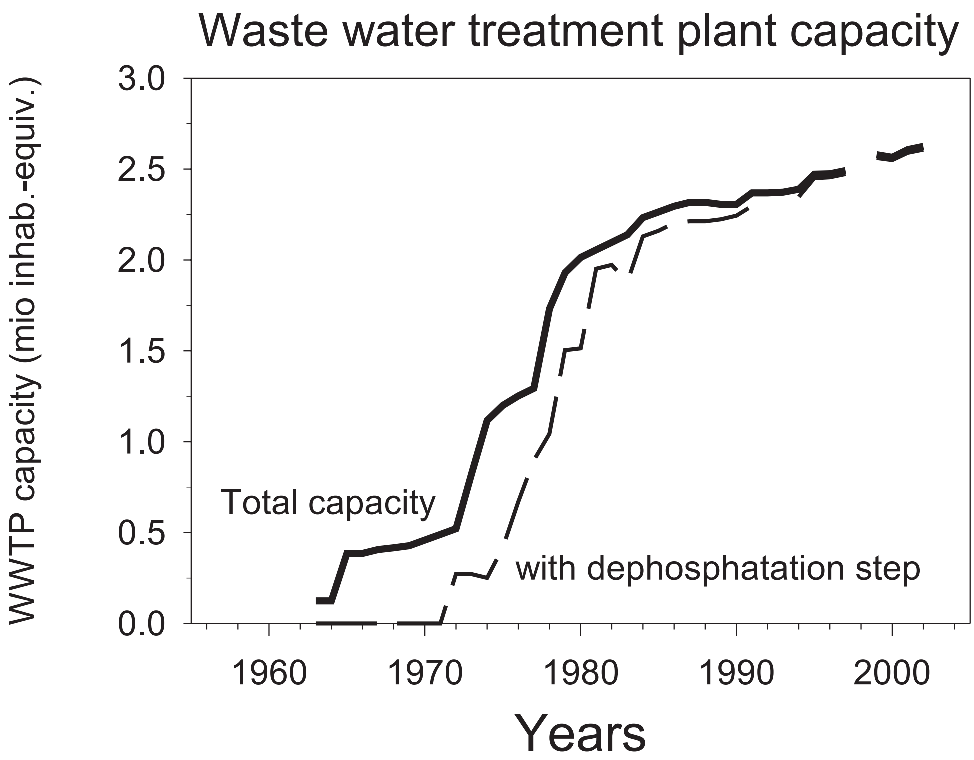

Figure 5 Evolution of the implementation of the wastewater treatment plant in Lake Geneva watershed. In 1971 phosphate removal was first introduced in WWTP scheme. Presently more than 99% of the WWTP capacity includes phosphorus removal.

Since the beginning of the 20th century, phosphorus and nitrogen have been known or suspected to be limiting factors in the primary production (algal growth) of lakes. However, Vollenweider's work (Vollenweider, 1968) and the enrichment experiments carried out in the Experimental Lakes Area (northwest Ontario) by Schindler *et al*. (1973) ultimately demonstrated that phosphorus was the key factor for controlling eutrophication in lakes. In Lake Geneva's watershed a set of measures were taken to control phosphorus point sources and diffuse inputs: i) since 1971, a third treatment step has been added to the treatment scheme to remove phosphorus from wastewater (Fig. 5), ii) changes in agricultural practices have been implemented, especially with respect to reduction of soil erosion and the use of fertilizers. A management objective of CIPEL is to reduce the mean phosphorus concentration in the lake water to below 20 $\mu g\ l^{-1}$, in order to control primary production effectively.

No special measures have been taken to reduce nitrate inputs to the lake, except recommendations for careful use of fertilizer in agriculture. This policy was based on the premises that i) the fertilizing potential of nitrogen can be effective only in the presence of phosphorus, ii) some Cyanobacteria species can fix elementary nitrogen and therefore nitrate input reduction would not be an efficient measure to reduce primary production (Rapin *et al*., 1995). Phosphate is also more easily controlled and removed from wastewater than nitrate.

As a result of these measures, the steep increased of phosphorus concentration recorded between 1969 and 1972 was halted out and concentrations stabilized around 90 µg l^{-1} between 1977 and 1980. At this time the third period defined by the phosphorus trend commenced: i.e. the restoration period.

3.3 The restoration period

3.3.1 Chemical variables and indicators

The restoration programme enforced by governmental authorities resulted in a decrease in phosphorus concentration (Fig. 1, Slide 6). A maximum of 89.5 µg l^{-1} was recorded in 1979, and since then concentrations have decreased steadily to reach 34 µg l^{-1} in 2003. To accelerate the reduction of phosphorus inputs, phosphorus was banned from textile washing products in Switzerland in 1986. As a result, the concentration of phosphorus in wastewaters in Switzerland decreased by a factor of two within one year, and the phosphorus released by WWTP and storm outfalls was reduced by 40 per cent. The effect on Lake Geneva can be observed in the phosphorus concentration diagram (Fig. 1), which shows a higher rate of reduction from 1986 to 1998. Since then, phosphorus reduction seems to have slowed down. The reasons for this are not clearly understood yet. Further reduction in phosphorus load might be achieved by increasing the efficiency of the WWTPs (currently 87 per cent efficiency; target value 95 per cent) and a more rigorous control of diffuse sources.

As mentioned earlier, no special programme has been implemented for nitrogen reduction. Consequently, concentrations of both total nitrogen and nitrate have continued to increase until 1985 (734 µg l^{-1}) and 1989 (598 µg l^{-1}), respectively (Slide 7). Since then a small decrease has been observed with concentrations of 659 and 544 µg l^{-1} in 2002, respectively.

Meteorological conditions favoured mixing of the water column between 1979 and 1986, with overturns occurring five times during this period (Fig. 3, Slide 9). Between 1986 and 1999 there was no overturn. Despite the prolonged absence of mixing, DO was not totally depleted in the bottom layers. This contrasts with the situation between 1972 and 1978, when anoxia occurred only a few years after the last complete overturn. This probably reflects a reduction in the organic matter inputs (see below) to the lake bottom, which in turn necessitated less DO for mineralization. Alternative sources of DO (turbulent diffusion, river intrusion) might once again be sufficient to provide oxygen, and prevent anoxia, although it has been suggested that the decreased frequency of turbidity currents might reduce the speed of delivery of oxygen-rich water to the deep zones of the lake (Loizeau and Dominik, 2000). In 1999, a partial mixing occurred, which raised the DO concentration to 9 mg l^{-1}. Since then no overturn has occurred, and DO concentrations have fluctuated between 2 and 6 mg l^{-1}. Swiss legislation requires the oxygen concentration in the lake water to be higher than 4 mg l^{-1}, except under unfavourable climatic conditions.

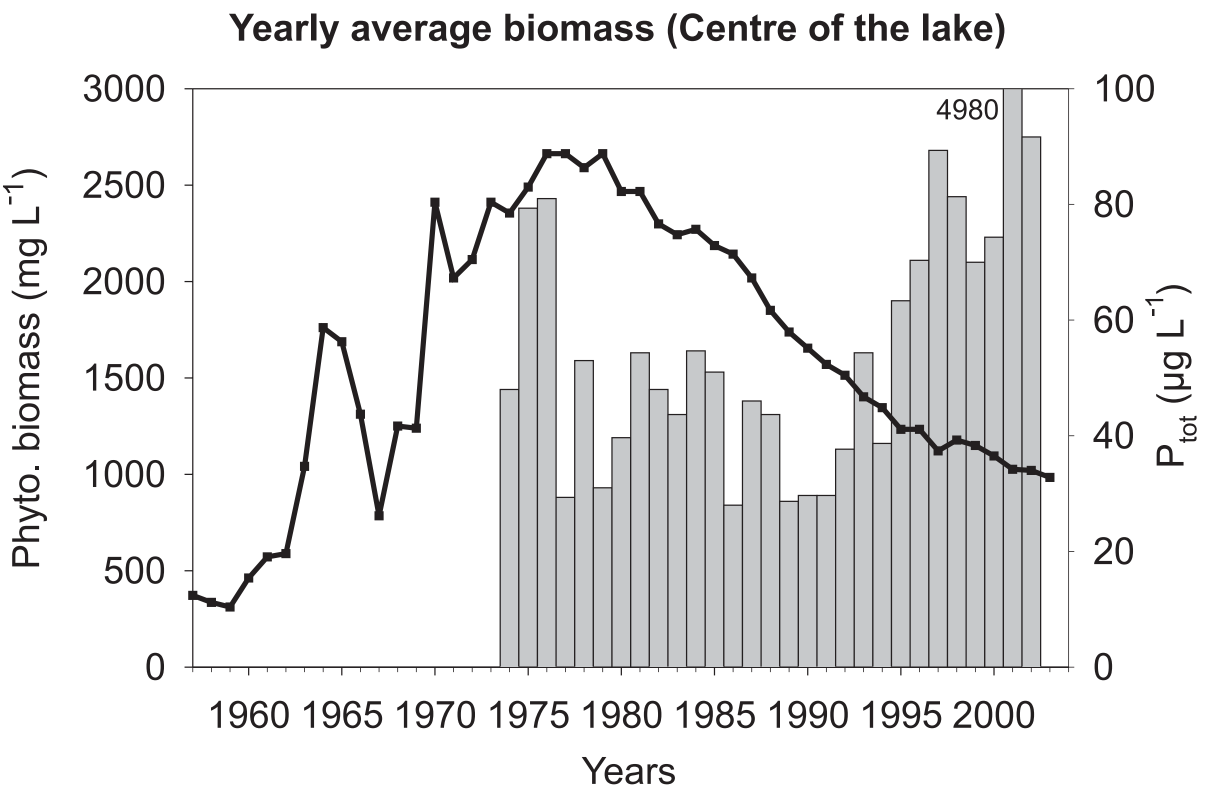

Figure 6 Evolution of the mean annual algal biomass at the lake centre. For comparison, the evolution of total phosphorus concentration in lake water is also shown.

There is no direct evidence (e.g. by flux measurements) of a reduction of organic matter inputs to the deep water. However it is assumed that this reduction has occurred, because both biomass and productivity have not diminished with time, whereas phosphorus loading has been reduced. Therefore faster recycling of nutrients through organic matter decay should occur in the water column to sustain productivity, and hence less organic matter should be transferred to the lake bottom.

3.3.2 Biological response to decreased nutrient concentrations

From 1981 to 1985, the phytoplankton communities were still dominated in summer by Dynophycea (*Ceratium hirundinella*), but Cyanobacteria also showed a net reduction. Conversely, Chrysophycea (for example *Dinobryon sociale*) and Cryptophycea (typical nanoplankton) tended to re-emerge (Anneville and Pelletier, 1999; Anneville *et al*., 2002). These changes are reflected in the moderate biomass reduction at the centre of the lake between 1976 and 1990 (Fig. 6, Slide 11). *Ceratium hirundinella* was responsible for blooms recorded in 1975 and 1976, and its subsequent decline is echoed in the decrease in biomass up to 1990. However, since 1992, despite the continuous fall in phosphorus concentrations, the mean annual algal biomass has increased again. In parallel, the relative biomass of oligotrophic species has diminished, but their absolute biomass has shown an irregular but steady increase (Slide 17). It should be noted that these species are only a minute fraction (< 1 per cent) of the total phytoplankton biomass. Anneville *et al*. (2002) hypothesized that "the reverse upward-trend of phytoplankton biomass observed during the 1990s could have resulted from the conjunction of at least two factors interacting with the sharp extension of the P-depleted stratum: i) global warming, which led to milder winters and good summer meteorological conditions in the late 1990s; and ii) the large size and physiological tolerance of the otherwise "autumnal species". Summer communities were characterized by an increase of Chrysophycea, Zygophycea and Xanthophycea, and massive development of *Diatoma tenuis*, *Mougeotia gracillima* and *Dynobryon divergens* (Anneville *et al*., 2002).

Zooplankton biovolume (Slide 15) started to decrease after 1981, following closely the phosphorus concentration. In parallel, instability of the species succession re-appeared (Rapin *et al*., 1995). The reduction in zooplankton biovolume after 1981 is not really elucidated, because whereas the phosphorus concentration decreased, the phytoplankton biomass decreased only very moderately, and even increased after 1990, without an increase of the zooplankton biovolume. This decoupling between phytoplankton and zooplankton evolution is probably due to a change in the phytoplankton species, with large, filamentous species becoming dominant but being less suitable as a food source for zooplankton.

Macrophytes seem to have responded slowly to water quality improvements. Increases in species richness have occurred as well as the return of sensitive species such as Characea. However *Potamogeton pectinatus* remains the dominant macrophyte species (Rapin *et al*., 1995).

The response of the fish community, and especially of the Salmonidae and Coregonidae, is very difficult to evaluate, because many additional factors play a role in the development of fish populations, including lake stocking with fry and improved fishing techniques.

Benthic fauna have responded positively to the probable reduction in the organic matter flux to the sediment. In 1992, the relative abundance of "oligotrophic" worm species increased from 17 per cent in 1979 to 41 per cent in 1992, at a depth of 40 m. This recovery has also been observed at 150 m, but to a lesser degree. However, the relative abundance of oligotrophic species is still below characteristic level (70 per cent) of oligotrophic lakes (Lang and Reymond, 1992).

3.3.3 Effects of remediation measures

Large scale measures to reduce phosphorus inputs from both point sources (wastewater) and diffuse sources (agriculture) have been effective, with the mean concentration in the lake being reduced by a factor of three. The response of the phytoplankton, expressed as algal biomass, does not show the expected decrease but on the contrary has tended to increase over the last 10 years with an unprecedented peak in 2001 (annual mean of 5 mg l^{-1}) despite a substantial phosphorous reduction. Simultaneously, it has been observed that the vegetative season has become longer and phytoplankton are colonising the deeper water strata. It has been speculated that the phosphorus concentration above 30 $\mu g\ l^{-1}$ is still too high to prevent high algal productivity. Therefore CIPEL has proposed a "Plan of action 2001–2010" to maintain the momentum in phosphorus reduction, including sewerage system improvements and promoting the use of phosphate-free dish washing detergents. The 2010 objective is to suppress phosphorus concentration below 20 μg l^{-1}. Media campaigns are proposed to involve the population in the effort for phosphorus reduction. The state of progress of this plan of action is available on the CIPEL website at www.cipel.org.

4 Conclusion

The present case study has shown that within a decade, the whole ecosystem functioning of Lake Geneva has been modified by excessive loads of nutrients. All compartments of the aquatic environment have been impacted. The major changes occurred within a period of about 20 years during the degradation period, whereas it seems that the return to the pre-eutrophication situation, with the dominance of "oligotrophic" species, will take a much longer time. After 25 years of restoration, some indicators have shown improvement while others have responded slowly and erratically. Simple "textbook" relationhips between physico-chemical conditions (phosphorus, dissolved oxygen) and biota (phytoplankton, zooplankton, fish) are not always simple in the real ecosystem of a large deep lake. Although the concentration of phosphorus is a major parameter driving the lake ecosystem functioning, other factors are important in the lake recovery. Meteorological conditions and foreseen changes related to global warming will likely play a major role in the future.

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