HÄSSLEHOLM
COMMUNITY
MUNICIPAL OFFICE

THE RESTORATION

OF LAKE FINJASJÖN

Summary

After having lowered the sea-level twice to gain farmland and heavy nutrient load mainly from sewage, Lake Finjasjön in 1950 showed obvious signs of eutrophication. Through better sewage treatment the phosphorus load on the lake was strongly reduced, but yet the situation in the lake got worse. From around 1975 the lake each summer suffered from intense *Microcystis* blooms. The disk transparency during summer was normally only about 20 cm and the water-surface was often covered with a green spinach-like soup of algas. Great amounts of sediment on the bottom of the lake each summer leaked up phosphorus meaning that there were no lack of nutrients for the algae.

As a first attempt to restore the lake to a more nutrient-poor state a large dredging project was started. By removing the richest top layer of sediment, the phosphorus leakage from the lake bottom should be reduced. After two years dredging this method was abandoned because of poor results. Instead during autumn 1992 a new strategy consisting of external phosphorus load reduction and bio-manipulation was formed.

In June 1994 the cyprinide population after one and a half years bio-manipulation was reduced with about 80% by trawling. At that time 430 000 kg of cyprinides had been removed. Through a reduction of cyprinides the thought was that we should get an increase of zoo-plankton (food for cyprinides). With more zoo-plankton we should have less algae (food for zoo-plankton) and a better tranparency in the lake. The increased transparency should give the pescivores better conditions and a better chance to eat the cyprinides. The reduced amount of algae should also result in a reduction of the nutrient-leakage from the lake sediment.

The result was more than expected. The disk tranparency increased and was in the summer 1996 2,1 meter meaning that the lake could be compared to the best swimming-lakes in the district. Already 1994 just after the trawling was finished it was again possible to swim in the lake and the amount of blue-green algae was very low. To some extent the blue-greens were replaced by green algae and diatoms.

Besides the obvious effects in the lake, the bottom-leakage of phosphorus almost stopped completely. This indicates that this process (at least in this lake) was depending on the existence of algae in the lake.

The very good results from this project gives good support for the thesis that bio-manipulation could be used to a much greater extent as a mean to break the dominance of blue-green algae in eutrophic lakes.

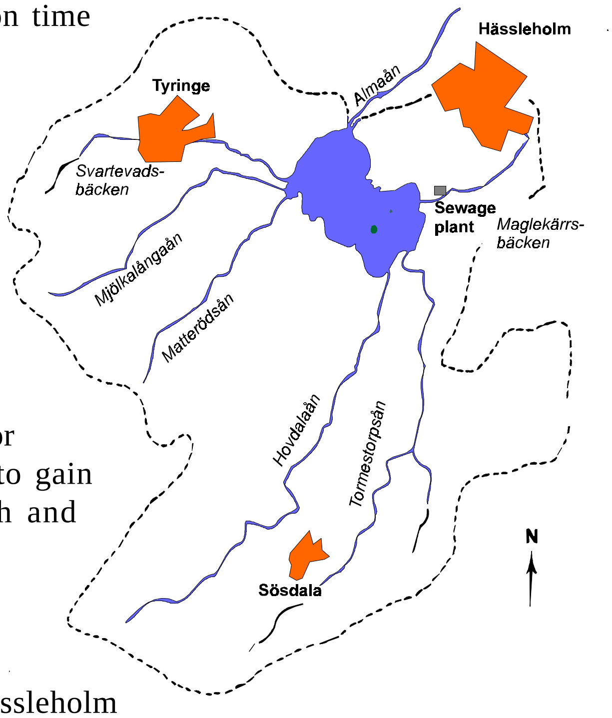
Background

Lake Finjasjön

Lake Finjasjön is a relatively shallow lake in the north part of Skåne (S. Sweden). It has an area of 11 km^2 and an average depth of 2,7 meters.

The lake dewaters an area of 250 km^2 through some minor streams where Tormestorpsån, Hovdalaån, Matterödsån, Mjölkalångaån and Svartevadsbäcken are the largest. Storm- and sewage water from Hässleholm, Tyringe, Sösdala and some minor villages (all together ab. 35 000 people) also runs to the lake. The yearly flow is about 160 Mm^3 resulting in a detention time of ab. 0,2 year.

DEWATERING AREA FÖR L. FINJASJÖN



Almaån is the only outflow. This stream runs to Helge å and then to the Baltic Sea in Hanöbukten.

Water level lowering

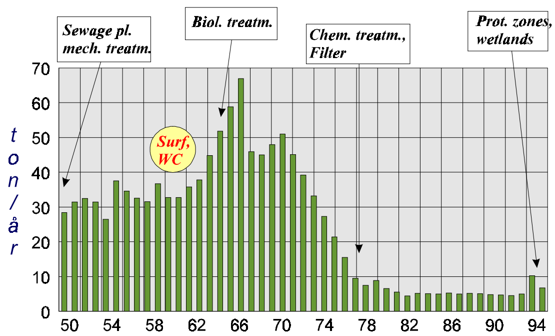
During the period 1850 to 1900 two major lowerings of the water level were done to gain farmland. This changed the lakes depth and extension.

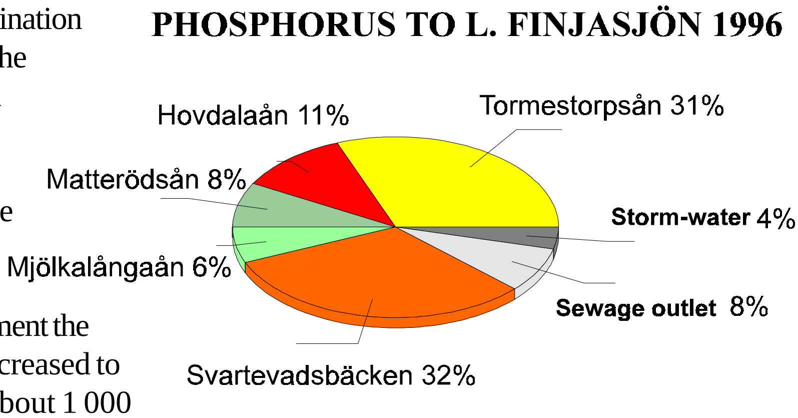
Nutrient load

From 1900 till now the population of Hässleholm changed from 2000 to 20000 people.

The first sewage plant with mechanical treatment was built 1949. It was then expanded with a biological step 1963 and a chemical phosphorus treatment plus a filter step in 1977.

PHOSPHORUS TO L. FINJASJÖN

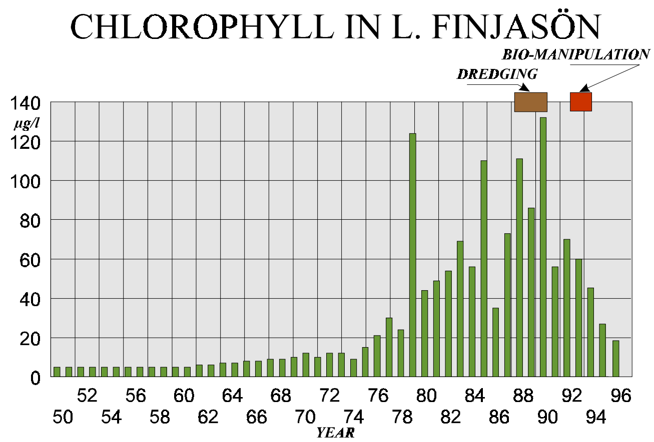




The increase in population in combination with better living standards led to the highest phosphorus load in the mid 60's. At that time near 70 000 kg per year reached the lake. Large parts of this was accumulated in the lake sediment.

After implementing chemical treatment the amount phosphorus to the lake decreased to about 5 000 kg per year. Of this about 1 000 kg came from sewage and storm water and the rest from woods and farmland. Through the wetlands Magle (additional sewage treatment) and Sjörröd (storm-water ponds) built in 1995 the part from Hässleholm was further decreased.

Algal bloom



Blue-green algae had existed in the lake for a long time, but around 1975 a period with yearly massive blooms of *Microcystis Wesenbergi* started. As the lake previously was appreciated for recreation and also used as source for drinking-water production this new phenomena was looked at with great anxiety. When the algae also turned out to be toxic and swimming was prohibited it seemed clear that if nothing else but the expansion of the sewage plant was done this problem would stay for a long time.

Lake restoration

In broad political consensus it was decided that Lake Finjasjön should be possible to swim in for "our children, in our time". Extensive investigations were made and after this it was decided that a large dredging project, aiming to remove the most nutritious sediment, should start.

Dredging

After a short test period the necessary structures were built for a large scale dredging project. Removing all the sediment would have been impossible from both technical and economical aspects, so the project aimed to remove the 0,5 m top layer (formed this century). The sediment revealed would then have about 30% lower phosphorus concentration and a higher Fe/P-ratio. This was believed to stop the great summer-leakage of phosphorus and as a consequence the algal bloom.

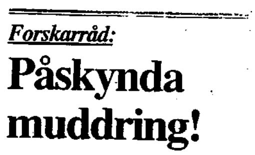
1. Sampling of sediment to determine water depth and depth of sediment top layer.
2. Building of a 3D surface model to control the dredging.
3. Suction dredging and pumping of sediment to primary ponds.
4. Pumping of surface water in sediment ponds to water ponds.
5. Returning water from water ponds to the lake.
6. Transportation of dried sediment to deposition the following season.

Dredging the whole lake like this was planned to take about 10 years. In short the dredging was carried out as described in square at the side. It started 1988 and was stopped 1991 when about 20% of the planned work was ready. The total cost for the project was then about 50 million SEK.


Kastar pengar i Finjasjön:
Experterna vill stoppa muddringen

Throwing money in the lake: Experts wants to stop the dredging

During 1990 it was more and more questioned if the dredging was an efficient method to stop the algal bloom in the lake. One important question was if the sediment leakage would be less then 30% (far from enough to stop the bloom) and another was if the algae resedimentation over dredged areas would reduce the effect of the work done. Many things indicated that these objections were correct and in 1991 they led to the termination of dredging project.


Forskarråd:
Påskynda muddring!

Advice from expert: Intensify dredging

Bio-manipulation

After having discussed the project with many experts an evaluation was done and as a consequence a new strategy was formed:

20 GÖINGE

Oenighet om rening i Finjasjön

Vill inte ha fiskeflotta

Dispute abou about lake restoration:
We don't want any fishing-fleet

■ As a long term part it was decided that the phosphorus load to the lake should be reduced with 50%. This should minimize the risk for algal blooms depending only on external load of phosphorus. This should be done by building protection zones along the part of the streams with intense phosphorus leakage from farmland, by rebuilding old sewage piping and by constructing wetlands for treated sewage and storm-water to the lake.

22 NORRA SKÅNE ★ Fredag 27 mars 1992

Politikerna sade ja till en fiskeflotta

5 ja mot 6 nej blev ett JA

Poiticial yes to bio-maipulation:
5 yes against 6 no became YES

The protection zones were achieved by renting a 5 m wide zone along the stream from the farmers for a period of 10 years. On this zone no crops were aloud to be grown. Expert advice about suitable fertilization on the farm as a whole was also included in the contract. This was done along Tormestorpsån, Hovdalaån and Svartevadsbäcken.

Nr 79 19

Stormöte stoppar trålning?

Fiskevårdsföreningen innehar fiskerätten

Finjasjöns fiskevårdsförening vill ha ett ord med i laget om utfiskningen som planeras. Föreningens närmare nio hundra medlemmar är kallade till stormöte på

Grand meeting stops trawling?
Fishery association owns the rights to fish:
"We can't stop the community to buy the trawlers or to launch them, but one thing is clear... We decide if they have the right to fish in the lake or not."

Sidan 6

Wetlands in Magle (30 ha) for additional sewage treatment and Sjörröd (10 ha) for treating storm-water were taken into operation in February 1995.

■ To achieve a rapid change in the lake we also suggested a bio-manipulation project in the lake, where the cyprinides (mainly roach and bream) should be reduced with 80%.

The bio-manipulation started in October 1992 and finished in June 1994. It was carried out as pair-trawling with “Mörten”[The roach] and “Braxen”[The bream] - two flat-bottomed boats modified by us for trawling and sorting of the fish on-board.

On each boat a professional fisherman accompanied by people from our own staff were doing the work. As efficiency was the key to success the work was partly done in double-shifts, fishing at night was tried during a period and additional smaller boats were used in the more shallow parts in the lake.

A fine-meshed trawl was used and after bringing the fish up all pescivores were put back in the lake. The main part of the cyprinides was delivered to a fish-food industry and by them sold to zoological parks.

After one and a half year of fishery the catches were reduced from about 3000 kg/day to 500 kg/day. This was regarded as proof for a 80% reduction. At that time 430 000 kg cyprinides had been removed from the lake. At that time most of the blue-greens had disappeared and as a result of this the bathing ban was lifted. All our measurements clearly showed the changes in the lake. The improvement continued over 1995 and -96.

Of special interest is that when the concentration of blue-greens decreased the phosphorus leakage from the sediment almost stopped. This could indicate that a major part of a lakes internal load is in fact generated by its biology.

The cost for the bio-manipulation was about 5 million SEK plus the buy of the boats and conversion of them (3 million SEK) of which parts can be regained from selling or hiring them to similar projects. As the lake now is in a clear-water state with radically improved transparency submerged vegetation has spread and water-birds have returned to the lake. This is also true for the human summer visitors. A water quality compared with other lakes in the community shows that L. Finjasjön from earlier having been one of the “worst” now is one of the “best” lakes.

Sampling program

A very extensive sampling program for follow-up and project evaluation started in summer 1988 and has then with minor changes been running.

Concentrations and water levels in streams to and from the lake have been measured weekly. The measuring points have been in all the major streams, the sewage plant outlet, and a small stream carrying storm-water from Hässleholm. Analyses included total phosphorus, phosphate, total nitrogen, ammonia, nitrate, iron, pH and COD_{Cr}. Water level were recalculated to water flow. Each year mass balances for water, phosphorus and nitrogen were established from these measurements.

Sampling in the lake included at the start one point in the north part of the lake and one in the south. In both these points samples at the surface and bottom were taken. The sampling freqency was 1/ week during april to november each year. Fractions of phosphorus and nitrogen, pH, COD, iron chlorophyll, temperature, disk transparancy and oxygen was measured. From 1992 algal biomass, algal diversity and zooplankton was added.

In the following part a summary of these measurements will be presented to meet the great interest for these data.

Mass balances 1988-96

The following two tables shows the concentration changes in the streams to and from the lake as yearly average values.

Total phosphorus µg/l	1988	1989	1990	1991	1992	1993	1994	1995	1996
Tormestorpsån	61	54	43	42	43	41	44	42	40
Hovdalaån	35	29	24	23	27	30	28	30	25
Matterödsån	35	29	18	22	20	24	24	17	19
Mjölkalångaån	37	26	19	20	20	22	22	15	19
Svartevadsbäcken	30	34	28	27	23	31	30	30	32
Sewage plant	175	154	132	130	124	144	158	140	105
Storm-water	60	60	60	60	60	60	60	50	50
Almaån	194	106	145	99	87	73	46	33	30

Total nitrogen mg/l	1988	1989	1990	1991	1992	1993	1994	1995	1996
Tormestorpsån	2,51	2,78	2,88	2,88	3,22	2,84	2,65	2,77	2,89
Hovdalaån	1,55	1,68	1,89	2,40	2,09	2,04	1,77	1,70	1,91
Matterödsån	1,25	1,36	1,45	1,62	1,44	1,41	1,22	1,18	1,47
Mjölkalångaån	1,84	1,89	2,08	2,04	2,20	1,90	1,81	1,87	1,77
Svartevadsbäcken	1,84	2,06	2,28	2,30	2,29	2,22	2,10	2,07	2,05
Sewage plant	21,5	21,1	20,7	20,1	19,5	21,5	18,5	15,6	17,6
Storm-water	3,50	3,50	3,50	3,50	3,50	3,50	3,50	3,00	3,00
Almaån	1,47	1,51	1,67	1,75	1,49	1,59	1,38	1,26	1,18

In Tormestorpsån there was a change in 1989-1990. This happened before the protection zones were established (1995). Through the Magle wetland (1995) the load from the sewage plant) was reduced. Storm-water has also been reduced as a result of Sjörröd wetland for storm-water treatment. Almaån is the outflow from the lake, and here the changes through the bio-manipulation are very obvious.

The situation for nitrogen is much the same. Except for the effects of the wetlands the changes in the inflow to the lake are small, while there is a drastic change in the outflow due to the bio-manipulation. The mechanisms for this reduction are unclear, but the increase of submerged vegetation (2 to 30% surface coverage) is probably an important factor. Besides plant uptake of nitrogen the submerged vegetation might have increased the denitrification rate in the lake.

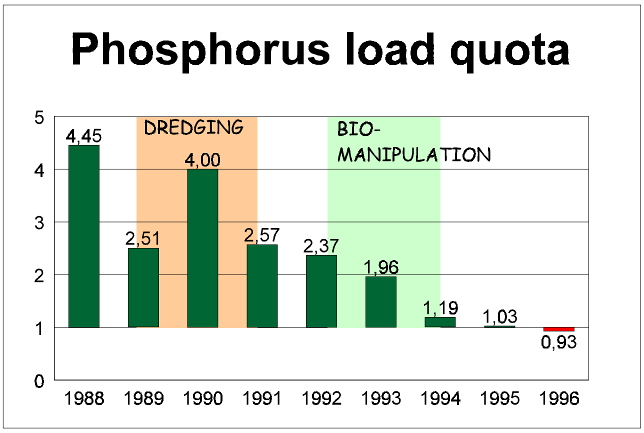
The following three tables shows transportation of water, phosphorus and nitrogen.

Flow Mm3	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
Tormestorpsån	41	21	32	36	35	47	67	42	35
Hovdalaån	51	27	36	49	47	35	84	43	21
Matterödsån	18	9	16	13	9	13	27	14	19
Mjölkalångaån	29	15	10	8	9	9	21	21	13
Svartevadsbäcken	33	17	24	21	22	25	62	57	43
Sewage plant	7	5	6	6	5	5	6	6	3
Storm water	6	6	6	6	6	7	6	6	4
Inflow	**185**	**101**	**130**	**139**	**133**	**141**	**274**	**188**	**139**
Almaån(outflow)	**196**	**102**	**125**	**125**	**125**	**146**	**248**	**202**	**135**
Ackumulated	**-11**	**-1**	**5**	**14**	**8**	**-5**	**26**	**-14**	**4**

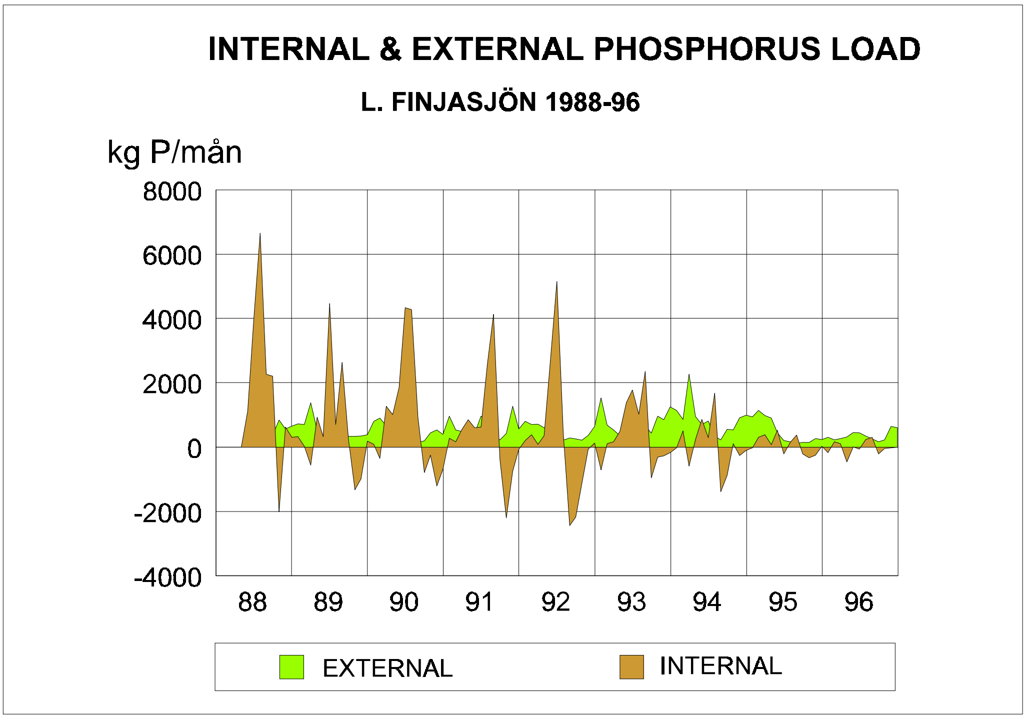
Total phosphorus ton	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
Tormestorpsån	2,5	1,1	1,4	1,5	1,5	1,9	3,0	1,8	1,4
Hovdalaån	1,8	0,8	0,9	1,1	1,3	1,1	2,4	1,3	0,5
Matterödsån	0,6	0,3	0,3	0,3	0,2	0,3	0,6	0,2	0,4
Mjölkalångaån	1,1	0,4	0,2	0,2	0,2	0,2	0,5	0,3	0,3
Svartevadsbäcken	1,0	0,6	0,7	0,6	0,5	0,8	1,8	1,7	1,4
Sewage plant	1,2	0,8	0,8	0,8	0,6	0,7	1,0	0,9	0,3
Storm water	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,3	0,2
Inflow	**8,5**	**4,3**	**4,5**	**4,8**	**4,6**	**5,4**	**9,6**	**6,4**	**4,4**
Almaån(outflow)	**38,1**	**10,8**	**18,2**	**12,4**	**10,9**	**10,6**	**11,5**	**6,6**	**4,1**
Ackumulated	**-30**	**-7**	**-14**	**-8**	**-6**	**-5**	**-2**	**-0**	**0**

Total nitrogen ton	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**
Tormestorpsån	103	59	93	105	113	133	178	116	103
Hovdalaån	79	44	67	117	98	72	148	73	40
Matterödsån	22	13	23	21	13	18	33	16	28
Mjölkalångaån	54	29	20	16	20	17	39	39	24
Svartevadsbäcken	61	36	55	47	50	56	130	119	88
Sewage plant	144	107	120	118	97	107	114	96	57
Storm water	21	21	21	21	21	25	21	18	12
Inflow	**484**	**309**	**400**	**447**	**412**	**428**	**663**	**476**	**351**
Almaån(outflow)	**287**	**154**	**209**	**219**	**186**	**233**	**341**	**254**	**160**
Ackumulated	**197**	**155**	**192**	**228**	**226**	**196**	**322**	**222**	**191**

As can be seen the amounts of phosphorus to the lake have been relatively stable during the period. The inflow of nitrogen was lower during 1996 and the outflow of both phosphorus and nitrogen was lowered due to the bio-manipulation.



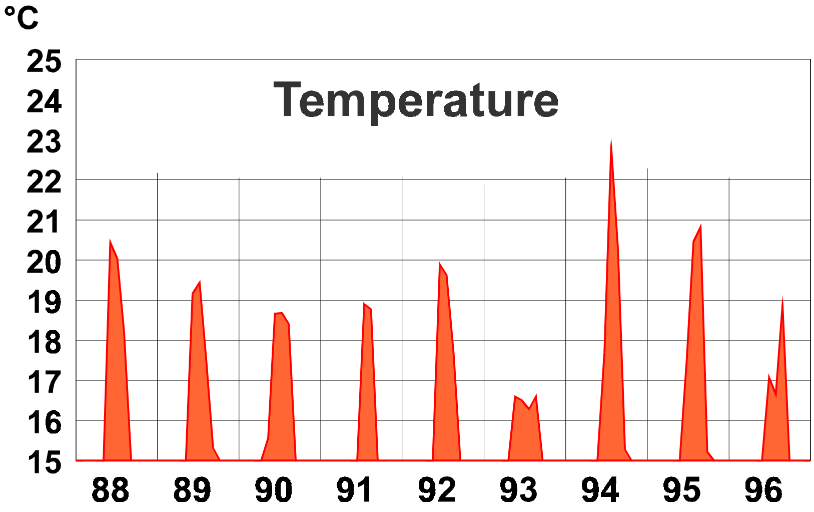
One way to measure the phosphorus status in the lake is the load quota, that is the mass-quota betwen outflow and inflow of phosphorus. If this is over 1,0 it indicates internal load from the sediment and if it is below 1,0 phosphorus is accumulated in the sediment. As can be seen in the graph this quota has changed during the bio-manipulation from above 2 to near 1,0. The thesis that internal load was reduced by the bio-maipulation is also supported by the mass balance.



Samples in L. Finjasjön 1988-96

Temperature

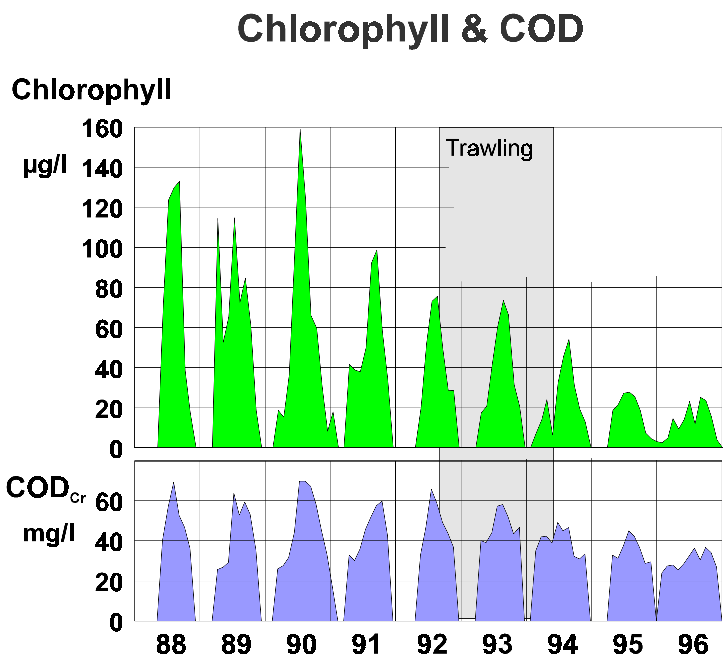
The period -88 till -92 had normal water temperatures with the highest for 1988 and 1992. The summer 1993 was extremely low while 1994 and 1995 were higher than normal.



Chlorophyll and COD

During 1992 the chlorophyll concentration was lower than expeted. The water level this summer was extremely low and this can possibly explain this fact. COD and phosphorus showed normal levels.

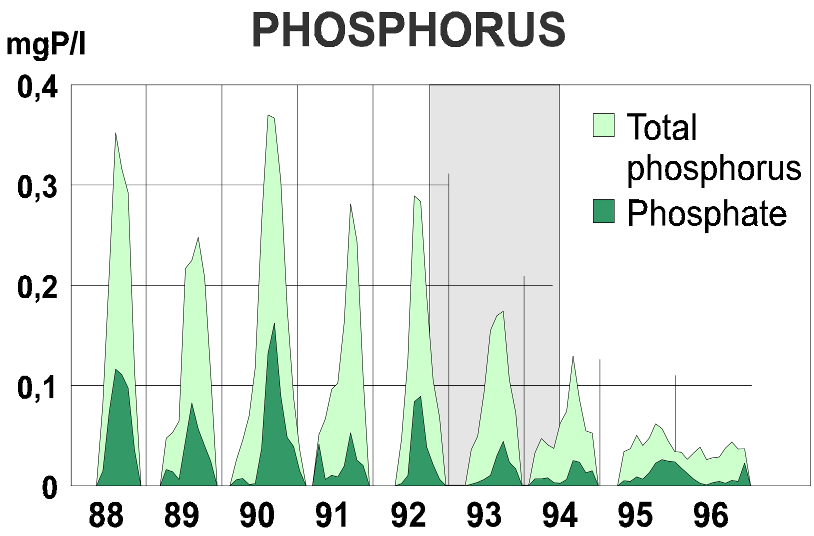
During the trawling the COD level decreased from about 70 to 40 mg/l and the reduction for both chlorophyll and COD continued over the whole period (the low levels for -96 however might be affected by the cold summer). After the bio-mainpulation normal summer concentrations of chlorophyll were near 20 µg/l.



PHOSPHORUS AND INTERNAL LOAD

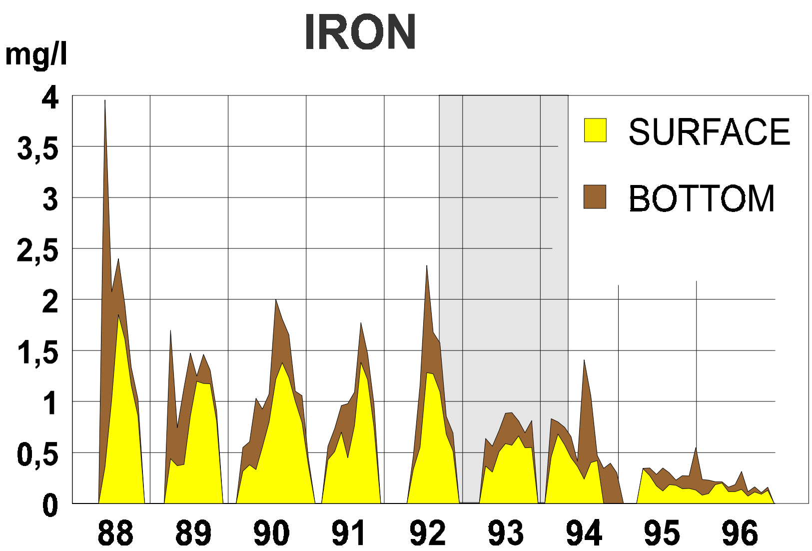
The reduction in total phosphorus and phosphate can clearly be seen as an effect of the trawling.

The lakes peak concentrations before the trawling were always near 300 µg/l and after the level seem to be between 30 and 40 µg/l which is equal to the average inflow. The peaks that can be seen is the result of internal load. As can be seen there was no internal load during -95 and -96. At the same time phosphate levels dropped.



An important phophorus fraction in the lake sediment is iron phosphate. Therefore we also measured iron in the water.

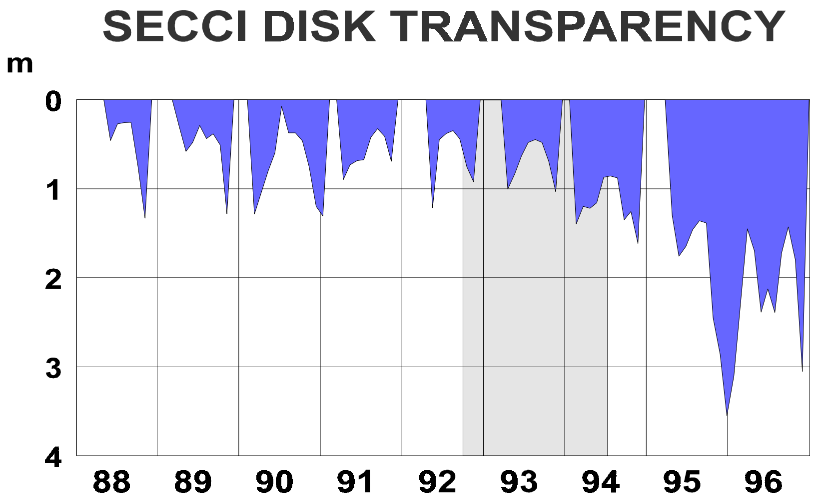
As the levels of iron in the inflow are low, this concentration can be regarded as an indirect measurement of internal load. As the graph shows, this concentration also has decreased during the bio-manipulation.



Indirect effects of reduced algal concentrations

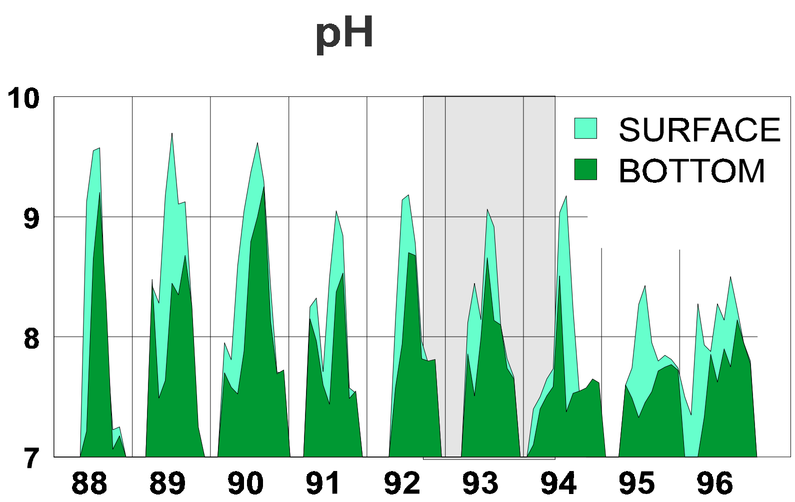
The disk transparency radically increased after the trawling from earlier summer levels 30-40 cm now the normal values are between 150 to 200 cm.

The increase of transparency also led to that submerged vegetation spread out from earlier 2% to 30% (1996) surface coverage in the lake.

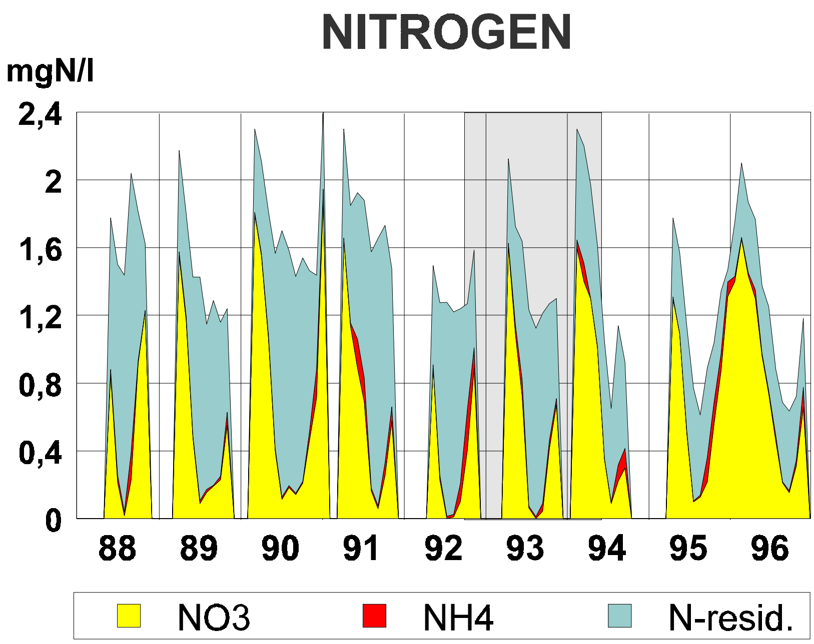


Through less algal photosynthesis pH in lake is approximately one unit lower in summer.

The oxygen concentration at the lake bottom (12 m deep) don’t seem to correlate with the trawling. These variations (in L. Finjasjön) seem to depend only on how long stratification we have in summer and the water temperature.



Nitrogen concentrations have developed in an interesting way. The nitrate reduction during summer does not seem to have changed and the same goes for ammonia. Earlier most of the reduction of nitrate was compensated by an increase of algal bound nitrogen, but after the trawling this fraction is much lower resulting in low total nitrogen concentrations in summer. During 1995 and 1996 the outflow concentrations were significantly lower. Uptake from the increasing submerged vegetation is a possible explanation.



It is also possible that the vegetation provides better condition for denitrification bacteria and the reduction seen is a change from algal uptake to denitrification.

SUMMER AVERAGE CONCENTRATIONS

As base for this value the average for weeks 23 to 35 for each year have been used. This means with a few days variation the period June to August. The following table shows average for the surface samples.

Year	Total nitrogen mg N/l	Nitrat mg N/l	Ammonia mg N/l	Total phosphorus mg P/l	Phosphate mg P/l	Transparency m
1988	1,7	0,3	0,040	0,225	0,067	*0,33*
1989	1,3	0,2	0,017	0,156	0,046	*0,40*
1990	1,8	0,2	0,012	0,276	0,049	0,33
1991	1,8	0,6	0,111	0,118	0,011	0,63
1992	1,3	0,1	0,018	0,225	0,059	0,39
1993	1,4	0,2	0,034	0,142	0,015	0,50
1994	1,0	0,2	0,051	0,093	0,015	0,89
1995	0,8	0,2	0,009	0,046	0,009	1,49
1996	0,9	0,5	0,019	0,031	0,003	2,10

Year	Chlorophyll µg/l	COD Cr mg/l	Iron mg/l	pH	Oxygen mg/l	Temperature °C
1988	124	56	1,04	9,44	10,7	19,8
1989	74	45	0,83	9,31	10,7	18,5
1990	161	71	0,78	9,42	11,2	18,9
1991	61	45	0,59	8,42	9,5	17,1
1992	63	59	1,05	9,08	9,9	19,2
1993	65	56	0,52	8,78	9,7	16,6
1994	45	48	0,30	8,78	9,2	21,3
1995	27	42	0,16	8,23	9,0	19,7
1996	19	33	0,11	8,29	9,3	17,5

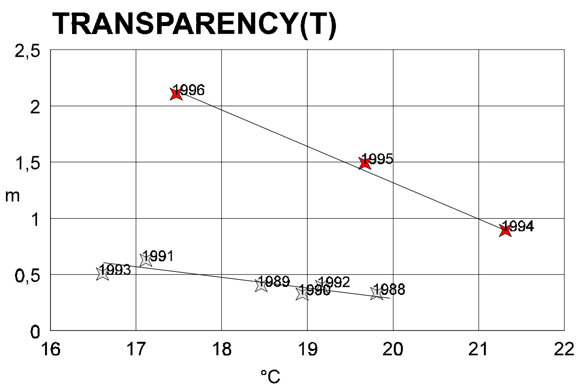
The following table shows summer average for the bottom samples.

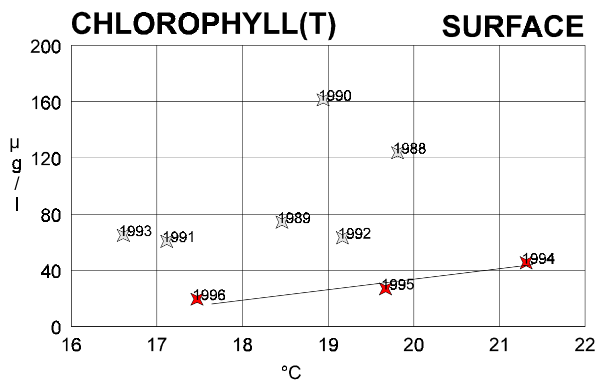
Year	Nitrate mgN/l	Ammonia mgN/l	Total-phosphorus mgP/l	Phosphate mgP/l	Iron mg/l	pH	Oxygen mg/l	Temperature °C
1988	0,2	0,490	0,317	0,192	3,21	8,24	3,2	16,4
1989	0,3	0,404	0,170	0,077	1,33	7,91	3,9	16,5
1990	0,2	0,428	0,220	0,073	1,24	8,27	3,1	16,5
1991	0,6	0,396	0,133	0,029	1,00	7,81	4,6	15,3
1992	0,1	0,168	0,266	0,065	1,84	8,27	2,6	16,1
1993	0,3	0,118	0,147	0,026	0,83	8,26	5,7	15,6
1994	0,2	1,116	0,268	0,147	1,00	7,65	4,1	16,6
1995	0,2	0,233	0,066	0,032	0,31	7,44	0,8	16,2
1996	0,4	0,173	0,052	0,018	0,21	7,77	5,9	15,2

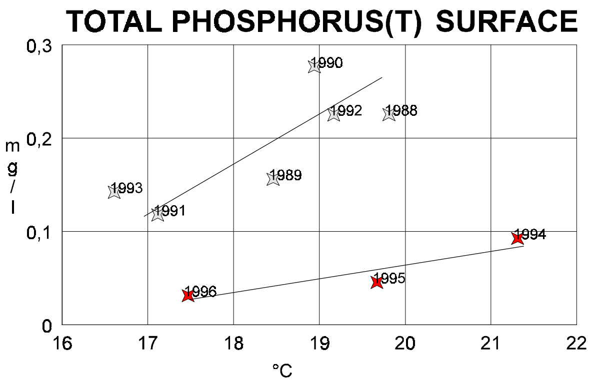
Note: Disk transparency for 1988 and 1989 were not measured within the program. These values are calculated from monthly measurements in combination with a model (for this lake) for relating this parameter to the measured concentrations of chlorophyll and total phosphorus. They should, however, be very accurate.

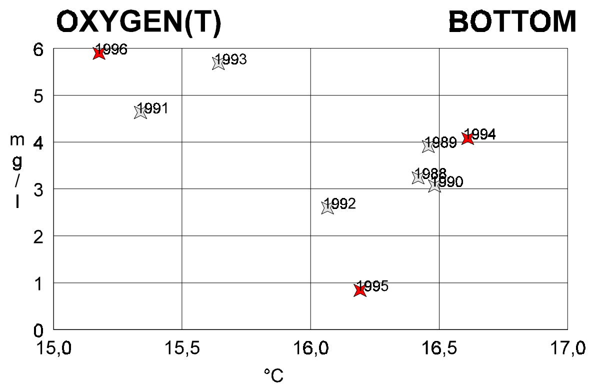
Temperature variations for summer average concentrations

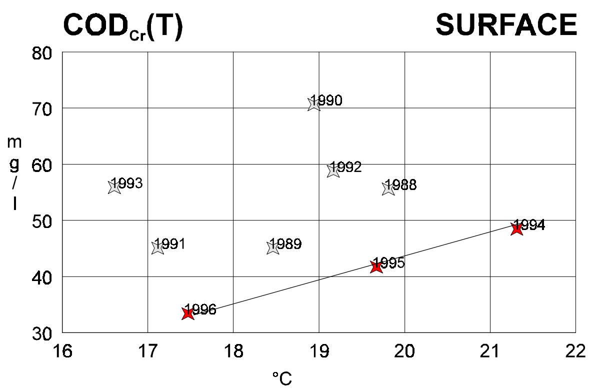
Before trawling most parameters correlated rather well with water temperature. After this the correlations are still good, slopes and intercepts are different. The graphs below illustrates these changes.

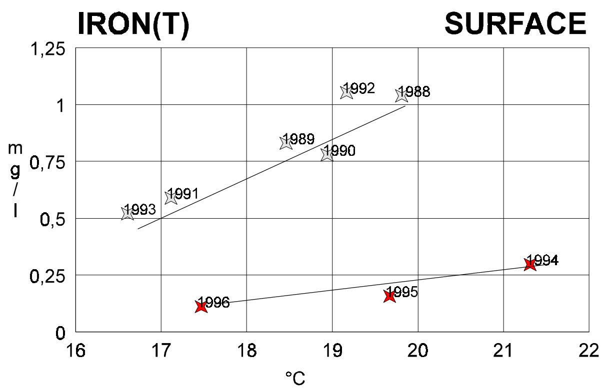












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