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HYDRAULIC LOADING, NUTRIENTS AND PHYTOPLANKTON IN THE HIRSEL LOCH (BERWICKSHIRE) - A REVIEW OF WORK DONE AND RECOMMENDATIONS FOR FUTURE STUDIES IN THE LIGHT OF A PROPOSED LOWERING OF THE WATER LEVEL

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Report to Scottish Natural Heritage (March 1994)

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Contents

Summary

1. Even without the occasional extra throughput of water at times of flooding in the Lithtillum Burn (draining an area of *ca* 530ha), the Hirsel Loch is well-flushed; a desk analysis of the 'immediate' catchment (90ha) and preliminary bathymetric survey suggesting a mean depth of only 0.4m, resulted in a flushing value of 4.9 loch volumes y^{-1}. Nevertheless, the mean hydraulic retention period of 74 days calculated from this suggests that there are periods providing ample time for phytoplankton to accumulate biomass and for nutrients released from the sediments to build up their concentrations, and this is borne out by the field data.

2. A very preliminary desk analysis of the catchment suggests that much of the land is likely to lose P - the nutrient most commonly limiting phytoplankton growth in temperate waters - at a rate of *ca* 0.25kg ha^{-1} y^{-1}; this gives a total P loading of between 18kg and 29kg depending on whether the 'immediate' drainage area or this plus 10% of runoff from the 'extended' catchment is used. The mean influent total P concentration of 80μg l^{-1} which would be expected to result from either of these runoff situations, is in reasonable keeping with the mean concentration of 114μg l^{-1} measured in the main feeder stream and the much lower figure of 18μg l^{-1} for that in a minor inflow. The runoff loadings are considerably less than what is likely to be the total external loading of P onto the lake, however, bearing in mind that over-wintering geese are likely to bring a further 65kg into the system. Then, the P loading approaches the current value of 1g m^{-2} y^{-1} for Loch Leven which is some 10 times the depth of the Hirsel.

3. Seasonal changes in 1986-1988 in the concentrations of key phytoplankton nutrients - soluble reactive phosphorus (SRP) and dissolved silica (SiO_2) - are extremely marked, with considerable contrasts between the ranges of values measured in the feeder streams (3-163μg l^{-1} and 6-13mg SiO_2 l^{-1}) and those recorded in the loch itself which are augmented by releases from the sediments (5-1137μg l^{-1} and 0.05-27mg SiO_2 l^{-1}). The maxima are as much a function of the shallowness of the loch, however, as the observed net release rates of *ca* 4-12mg SRP l^{-1} d^{-1} and 35mg SiO_2 m^{-2} Nevertheless, the annual mean in-lake SiO_2 concentration of 14.5mg l^{-1} could be achieved as a result of very feasible loss rates of 40kg ha^{-1} y^{-1} from the land. The in-loch peaks of both nutrients are as high as any measured so far in Scotland, and the silica figures rank with the world's highest for surface waters.

4. Qualitative and quantitative features of the phytoplankton reflect the rich (hypertrophic) status of the loch. Overall biomass measured as $chlorophyll_a$ concentration has exceeded **1mg** l^{-1} on occasions, with correspondingly dense populations ($10^4 ml^{-1}$ - $10^6 ml^{-1}$) of small unicellular centric ('pill-box') diatoms,

chrysoflagellates and mixed assemblages of green algae and cryptomonad flagellates, or sparser numbers of very large filamentous algae.

5. It is not known to what extent the amounts of silica attributed to sediment release stem ultimately from dissolution of planktonic or epiphytic diatoms, or from reed tissue, but the influence of the higher plants on the ecology of the loch is likely to be considerable. As such, any spread of reed beds consequent upon a proposed lowering of the water level, could be important.

6. In that the mean depth of the loch is *ca* 0.4m, the proposed lowering of the water level by 15cm represents a decrease of nearly 40%, and what is more, to a depth of only 25cm which may increase the likelihood of drying up in addition to an ingress of rooted vegetation.

7. A reduction in lake water level would impact on a considerable variety of interacting physical, chemical and biotic components of the Hirsel Lake; some of the possible changes are discussed with the main focus on immediate effects of reductions in lake volume and water depth and the longer term consequences of an eventual ingress of fringing vegetation into the lake.

8. If the actual impacts of water level alteration are to be assessed, and the general effects predicted in this report are to be evaluated, it is essential that inventories of the physical, chemical and especially the biotic components of this loch be obtained. A wide range of studies which would increase basic scientific knowledge and enhance our ability to manage small wetlands of the Hirsel type, are recommended.

INTRODUCTION

The main aims of this report are as follows:

(i) to collate, analyse and interpret nutrient and phytoplankton data collected in the late 1980s

(ii) to assess the general trophic status of the loch on the basis of phosphorus levels and planktonic algal abundances in particular

(iii) to relate the findings from (i) to features of the catchment that have a bearing on nutrient loadings to, and the rate of throughput of water in, the loch

(iv) to assess the likely impacts of a proposed lowering of the water level in the loch, on nutrient and algal levels.

Since nutrients and phytoplankton feature prominently in this study, it is worth considering which nutrients are of major interest, and why. The nutrients mainly fuelling the production and growth of phytoplankton are phosphorus (P), nitrogen (N) and silica (SiO_2). However, while each of these can be reduced to growth-limiting levels in lochs, shortage of SiO_2 ultimately affects only the diatom component of the algal assemblages. Other algae, including many chrysoflagellates use silica but the diatoms are unique in having an absolute requirement for this element, such that cell division cannot take place in its absence (Sullivan and Volcani 1981). What is more, the silica content of many diatom species may exceed 50% of the total dry weight of the cells (Bailey-Watts 1988). Shortages of N can be circumvented by certain blue-green algae which can augment their N requirements by using atmospheric gaseous N dissolved in the water (Carr and Whitton 1982). P alone is required - mainly in the form of what is operationally determined as soluble reactive P (equivalent to inorganic ortho-phosphate) by all algae (and other plants). Hence, the overall productivity of many freshwater systems, and their annual mean levels of phytoplankton (measured as chlorophyll$_a$ concentration for example) are determined largely by the supply of P, and this nutrient is the main cause of lake eutrophication (OECD 1992).

Concern over water quality of the Hirsel Lake - which is one of the largest waterbodies in the area - relates to the fact that it has been designated an SSSI on account of the lowland bird roosting and nesting populations associated with the loch itself as well as its agricultural margins, nearby woodlands and running waters. In addition, the loch has recently been subject to three major planning enquiry cases relating to abstraction of water for irrigation, and the possible polluting effects of local poultry units and timber treatment yards. There has plainly been an increase in agricultural activity and fertiliser use in the catchment, although no data other than those presented below are available to substantiate to what extent these impact on the loch. There is a need to assess the indirect effect of the rich catchment (which has been agricultural in nature since the 12th century) in attracting birds that may exacerbate nutrient losses from the land by feeding near the lake and roosting on it. Peak bird counts (minimum estimates) for the winter 1992-1993 are as follows: 500-600 Mallards of which some 50% may feed at the loch, 300 Coots, 200 Shovelers, 200 Goosanders, 300 Whooper Swans, 130 Mute Swans, and a total of 5000 Greylag and Pinkfeet Geese.

THE STUDY SITE

The lake is 11.1ha in surface area. It is a reservoir with an embankment some 200m long. The outlet from the lake discharges to the Leet Water approximately 0.5km downstream; this river joins the Tweed 2km further down. A recent, very preliminary echo-sounding run along the length of the lake, suggests that the maximum depth is *ca* 1.2m. In the absence of data to the contrary, the mean depth is considered to be one-third of the maximum i.e. 0.4m. The lake lies in an area of lowland character (maximum 50m a.s.l.) with some afforestation. The area is essentially dry, with a long-term (1941-1970) mean annual rainfall value of 650mm. The 'immediate' catchment area (see below) as defined by consulting engineers is given as 95ha, although planimetry of the area at 1:25000 scale by this laboratory produced a figure of 89.7ha. During flood conditions, the neighbouring Lithtillum Burn which lies to the west and is outside the catchment as defined above, spills though a culvert and runs into the Hirsel. The extra area drained at such times amounts to some 530ha, so the spillage may constitute a significant proportion of the total inflow of water to the lake.

RESULTS AND DISCUSSION

Hydraulic loading and the external inputs of phosphorus and silica

In the absence of further details on hydraulic loading, one can only estimate a possible range in flushing rates and nutrient loadings - two of the most important determinants of the chemical and biological (trophic) status of lakes (Dillon and Rigler 1974). However, **Table 1** shows that a long-term annual mean flushing rate of 4.9 lake volumes and a total P loading of approximately 17kg y^{-1} are calculated assuming there is no overspill from the Lithtillum drainage area, and values of 7.9 lake volumes and 29kg y^{-1} are obtained assuming that some 10% of the water from the extra catchment area enters the Hirsel lake.

The Hirsel would be expected to be fairly rapidly flushed, not primarily on account of the ratio of the immediate catchment area to that of the lake which at 8.1:1 is about average, but because the lake is also so shallow. Indeed, the estimated value of 4.9 loch volumes y^{-1} is some two-and-a-half times the long-term figure of 1.9 measured for Loch Leven (Sargent and Ledger 1992), somewhat similar to the value of 7 estimated for Loch Dee (Bailey-Watts and Kirika 1993) although considerably less than that of 21.4 calculated for Loch Insh, for example (Bailey-Watts *et al* 1992). The water retention time (the reciprocal of flushing rate) estimated for the Hirsel - 74 days - suggests there is still likely to be plenty of time for algae to accumulate biomass, although actual levels will depend on light and nutrient resources which fuel the production of these organisms in the first place, while water throughput, sedimentation and grazing of cells determine what fraction of the production is observed. Any extra influx of water from the Lithtillum Burn will increase the flushing rate and P loading, but at the same time reduce the time available for algae to accumulate biomass. The specific

Table 1. Estimated flushing rates and total phosphorus loadings assuming (i) no overspill from the Lithtillum Burn into the 'immediate' catchment, and (ii) the introduction of 10% of the runoff from that extra drainage area.

Parameter	(i)	(ii)
runoff from the catchment (x 10^{-4} m^3 y^{-1})*	20.7	34.0
rain falling on the loch surface (x 10^{-4} m^3 y^{-1})**	1.1	1.1
total throughflow (x 10^{-4} m^3 y^{-1})	21.8	35.1
flushing rate (loch volumes y^{-1}):	4.9	7.9
theoretical retention time (days):	74	46
total P loading from land runoff (kg y^{-1})****	17.5	28.6
total P loading from 1350 geese (kg y^{-1})*****	65.8	65.8
total P loading : runoff plus geese (kg y^{-1})	83.3	94.4

* corrects for potential evapotranspiration (460mm, Meteorological Office), adjusted to 419mm (Institute of Hydrology Low Flows Report). ** as * and assuming that evaporation from the water surface is 20% greater than that from land. *** the sum of the products of each land use area and a P loss coefficient appropriate to that area. **** assumes this number of geese stay for 5.5 months, and each bird contributes 250mg P per day (Hancock 1982).

areal loadings of P, i.e. the loadings expressed as weights of P per square metre of loch surface, are 0.16 and 0.26g TP m^{-2} y^{-1} for the two situations envisaged in terms of catchment area. For waters up to 5m mean depth, the models of OECD (1982) and Vollenweider (1975, 1976) define 0.07 and 0.13g TP m^{-2} y^{-1} as respectively, the 'permissible' and 'dangerous' loadings of P; these terms refer to the likelihood of biological manifestations of eutrophication, such as algal blooms and overgrowths of attached algae or macrophytic vegetation, bearing in mind that increased biomass of plants rather than elevated concentrations of nutrients *per se* constitute the 'eutrophication problem'(Bailey-Watts 1994).

If the model equations can be extended to include waters as shallow as the Hirsel (see below), the present desk analysis suggests that this lake is receiving P from land runoff alone at a rate that is at least 'dangerous'. But these loadings are but fractions of the likely amounts of P brought in by geese (**Table 1**). If the likely influence of these birds alone (i.e. ignoring albeit probably relatively minor, inputs from other wildfowl) the total loadings may exceed 80kg y^{-1} with the figures for the two situations envisaged in the Table differing rather little since the relatively large contribution from geese is independent of catchment size. Even in the absence of runoff from the Lithtillum drainage area, the annual P input rate is equivalent to 0.75g m^{-2} y^{-1}, and thus some 10 times the permissible level and 5 times that considered dangerous. The specific areal figure also approaches the value of *ca* 1g m^{-2} y^{-1} which is likely to represent the current situation at Loch Leven which is some 10 times as deep as the Hirsel Lake. Since the Hirsel is so shallow, however, wind-induced disturbance and fish movements may bring sediment material into suspension and so affect the light climate to the disbenefit of phytoplankton production. Planktonic algal levels may therefore not necessarily reflect the high nutrient loadings and concentrations. Indeed, if the intrinsically high rate of flushing is taken into account with these other factors, primary producers in the Hirsel Lake would be expected to be dominated by rooted emergent vegetation and an associated epiphytic and periphytic microflora, rather that a free-living planktonic community.

Feeder stream and in-lake concentrations of phosphorus and silica, and the influence of 'internal' nutrient loading

In view of the fact that such a large proportion of the considerable burden of P to this lake enters in 'dry' form i.e. independent of water runoff, it is perhaps not surprising that the concentrations in the Hirsel are very high

Figure 1 shows **mg** l^{-1} levels of total P (**1a**), that is, all forms, dissolved and particulate combined, and of the soluble reactive fraction (SRP, **1b**), which is considered to be, at the instant of sampling, the form that is most immediately available to plants including phytoplankton. Note that SRP constitutes the majority of the TP at the peak levels, but is not so dominant when TP concentrations are relatively low.

A major feature of the temporal changes in P is the contrast between in-lake levels (measured on samples taken from the outflow) and the concentrations in the main feeder stream. This is in keeping, however, with what is thought to be the situation as regards the relative importance of the two main sources of P, with the minority entering *via* feeder streams. Indeed, when the land runoff loadings are divided by the volumes of water estimated to enter the lake (**Table 1**), mean influent concentrations of 80 and 81μg l^{-1} are obtained for situations i and ii respectively. These are of the order of the mean value of 114μg l^{-1} calculated for the main inflow, and are on 'the right track' in that the albeit very small inflow gave a figure of only 18μg l^{-1}. If, as in the case of rapidly flushed waters, there was little sedimentation of (particulate) P to the lake bottom, in-lake TP levels would be much the same as the estimated mean influent concentrations. In most waters at most times of the year, however, in-lake TP concentrations are usually somewhat less than the mean influent levels. This is plainly not so at the Hirsel Lake, and there are two main reasons for this.

The first reason relates to the additional input of P due to geese.
These birds theoretically raise the mean 'influent' P level to *ca* 382 and 270μg l^{-1} for the two situations as regards catchment area. These values are very high and exceed by some considerable amount the (summer) peak concentrations recorded in Coldingham Loch (Bailey-Watts *et al* 1987). Nevertheless, they fall far short of the mean figure of 696μg l^{-1} calculated for the Hirsel Lake itself. Moreover, it is likely that much of the P in goose faeces probably sinks rapidly to the sediments, and only after mineralisation is (some of the) P released in the form of inorganic phosphate. The second reason for the very high in-lake P levels almost certainly relates to this re-cycling of P. The mean daily rates of build-up of SRP to the main peaks shown in **Figure 1b** are 7.2mg P m^{-2} sediment surface between mid-March and early May 1987, 3.6mg P m^{-2} over September and October 1987, and 11.7mg P m^{-2} between mid-April and mid-May 1988. Increase in SRP concentrations attributed to sediment release at Loch Leven have reached 17.6mg P m^{-2} d^{-1} (Bailey-Watts, May and Kirika 1991), and a value of 8.7mg P m^{-2} d^{-1} was calculated from field data on Coldingham Loch (Bailey-

Watts *et al* 1987). The levels of P found in the Hirsel are much higher than those found in these other lochs, because such a shallow lake has less water in which the released nutrient can be distributed and diluted. Indeed, apart from Kilconquhar Loch in Fife which also exhibits P levels of around 1mg l^{-1} (Bailey-Watts *et al* 1992), the Hirsel Lake may prove to be one of the richest of Scottish standing waters.

The highest SiO_2 levels achieved in this loch approximate to 20mg l^{-1} (**Figure 2**). These are probably the highest of any measured in Scotland, and possibly the British Isles; indeed, they rank with the world's highest which are associated with volcanic regions such as the Far East (Livingstone 1963; Rawlence and Whitton 1977). As a comparison in Scotland, the annual maxima in Loch Leven rarely exceed 11mg SiO_2 l^{-1} (Bailey-Watts 1988; Bailey-Watts, Smith and Kirika 1989b). Recycling of this nutrient from the cells of diatoms and chrysophyte algae in the bottom deposits almost certainly contribute to the maximum concentrations although these do not always coincide with the SRP peaks.

The contrasting nature of the plots of the inflow and in-lake (outflow) SiO_2 levels suggest that re-cycling of the nutrient is important, and especially so bearing in mind that the dissolved SiO_2 represents what is left after use by algae at the instant of sampling. However, the mean in-lake level of this nutrient could be accounted for by runoff from the land. In contrast to the situation with P, where the concentrations in the lake are but a fraction of those measured in the feeder streams, the mean SiO_2 levels of 12mg l^{-1} in the main feeder stream and 8mg l^{-1} in the minor inflow are relatively similar to the mean in-lake figure of 14.5mg l^{-1}. To maintain this lake concentration, losses from the catchment of 36kg SiO_2 $ha^{-1}y^{-1}$ would be sufficient, and this rate approaches the lower end of the range measured for the Loch Leven sub-catchments i.e. 43 to 104kg SiO_2 $ha^{-1}y^{-1}$ (Bailey-Watts, Smith and Kirika 1989a).

The phytoplankton

While in common with P and SiO_2 concentrations, the phytoplankton has attained very high levels this is exceptional. Apart from an extraordinarily dense population of algae equivalent to >1mg chlorophyll$_a$ l^{-1} in spring 1988 the populations are very moderate (**Figure 3**). Indeed, the concentrations usually measured are in line with what might be expected for a rapidly flushed, though rich ('hypertrophic') waterbody - and one as indicated above, with a light climate not too conducive to high phytoplankton productivity.

Since the sampling interval operated for this limnological reconnaissance was often more than one month, the species composition of the phytoplankton could differ considerably between consecutive samplings. As a result, few trends in the population density of individual species that could be plotted as graphs were detected. The major population densities recorded and the main types of algae involved, are thus presented in **Table 2** which includes some observations on material collected in April 1985. On most of the sampling occasions not included in this Table included in **Figure 3**, algal densities were comparatively low. Indeed, detritus tended to dominate the particulate material at these times, and this often contains pigment leading to an over-estimate of 'true' chlorophyll$_a$.

The two major features of this plankton are the predominance of small organisms and - partly as a consequence of this - the very dense numbers attained. There are also some noteworthy features regarding some of the algal types recorded. The chrysoflagellate which dominated the scene in late July 1987 is of especial interest for two reasons. First, it is not easily assigned to any of the species described so far, although it could be an *Ochromonas*, but with an amoebo-flagellate stage. Second, each of the 73 individuals counted contained a centric diatom which the 'alga' had engulfed. The *Ankyra* which dominated the phytoplankton while overall crop densities were rather low in February 1988, was of interest in exhibiting spore formation; this heralds the end of its 'planktonic' existence.

DISCUSSION WITH SPECIAL REFERENCE TO THE POSSIBLE IMPACTS OF A LOWERING OF THE WATER LEVEL

The actual nature, timing and extent of changes due to a (seasonal) lowering of the water level of this small, shallow lake is impossible to predict with any meaningful degree of certainty. However, major components that are likely to be affected can be collated on the basis of the desk predictions about water throughput rates and P loadings, and the measurements of lake dimensions and nutrient and phytoplankton concentrations. **Figure 4** shows that a considerable variety of interacting physical, chemical and biotic factors are involved. It is presently envisaged that some changes will occur relatively rapidly as a result of the reductions in water volume (increased flushing, for example) and water depth (increased disturbance of sediment, and elevated concentrations of nutrients derived from the sediments). Other impacts (such as a shift from planktonic communities to attached, epiphytic and loosely attached microfloral and faunal assemblages) are likely to be manifested only later, and after the expected ingress of fringing vegetation towards the centre of the lake.

FUTURE RESEARCH

Although perhaps not universally appreciated, the composition and dynamics of biological communities, and the factors controlling these features, in small, shallow wetlands like the Hirsel Loch, are likely to be at the very least as complex as those in larger waters. In that this report has covered only a minuscule aspect of the loch, it follows that gaps exist in our knowledge about all aspects of its ecology and management. To some extent, research on - even basic descriptions of - the factors and processes encompassed in **Figure 4** are warranted. Indeed, without a much-improved inventory of a number of features, any changes consequent upon the lowering of the water level, could not be put into context. Indeed, our 'hypotheses' on the impacts could not be tested. However, the present study provides enough of a basis on which to select areas of research and monitoring that are especially worthy of attention.

Monitoring programmes

The existing data suggest that a reasonable picture of the temporal patterns of nutrients can be obtained from say, monthly or 6-weekly sampling - possibly at a lower frequency for the inflow(s). Information needed to assess the impacts of water level alteration on the biota requires more intensive treatment. There are very few groups of organisms that have been examined at all; there are data on only phytoplankton (this study), crustacean zooplankton (Jones 1989), and birds. As far as we are aware, there is no information on any of the other groups featured in **Figure 4**, so programmes of monitoring at intervals appropriate to the life-cycles of the organisms in question need to be initiated. 'Higher' plants and e.g. birds may provide the major clues to the functioning and dynamics of the Hirsel system and its overall responses to water level changes. On the other hand, the complex spatially and temporally changing populations and assemblages of lower algae and invertebrates are likely to reveal more about impacts on biodiversity and detailed trophic structure.

Table 2. The main types of phytoplankton and the population densities recorded in the Hirsel Lake 1985-1988.

Sampling date	**Phytoplankton species and estimated population densities**
April 1985	A dense assemblage of *ca* 600000 green chlorelloid unicells and tetrads ml^{-1}; 84000 chlamydomonads ml^{-1} and 60000 *Monoraphidium* ml^{-1}, and 170000 ml^{-1} of the cryptoflagellate *Rhodomonas.*
October 1986	Comparatively few algae but *Rhodomonas* dominant
February 1987	*Rhodomonas* again dominant at *ca* 22000 ml^{-1}, but with 7000 *Chlorella* ml^{-1} and approximately 3000 ml^{-1} each of unicellular centric ('pill-box') diatoms, chrysoflagellates and 'pico' plankters ($<1\mu m$).
March 1987	An assemblage dominated by 52000 unicellular centric diatoms ml^{-1}.
June 1987	A relatively sparse crop, but dominated by the green alga *Ankyra* - *ca* 4000 ml^{-1}.
July 1987	Another relatively sparse crop but interesting in being dominated by an alga-devouring chrysoflagellate numbering *ca* 15000 ml^{-1}.
February 1988	A mixed green algal crop with *Ankyra* dominant at *ca* 1000 ml^{-1}.
March 1988	An assemblage with *Rhodomonas* and other cryptoflagellates including *Chroomonas* and *Cryptomonas*, but dominated by the xanthophyte *Akanthochloris* - *ca* 6000 ml^{-1}.
early April 1988	Another assemblage dominated by a chrysoflagellate - probably a species of *Ochromonas* - and numbering *ca* 230000 ml^{-1}. This crop corresponds to the extraordinarily high pigment values measured in samples from the shore and the lake outflow.
late April 1988	A mixed population numerically dominated by very small green non-motile unicells (*ca* 730000 ml^{-1}) but with, in addition some 19000 ml^{-1} *Monoraphidium* (mainly *M. griffithsii* but with some *M. contortum*), and 13000 unicellular centric diatoms ml^{-1}.
July 1988	An unusual crop dominated by extremely large (millimetre dimension) filamentous algae of the Zygnematales group - in nevertheless very low numbers e.g. 10 ml^{-1}.

Research topics

Basic monitoring and descriptive studies of the type outlined above will spawn scientific papers - such is the nature of freshwater ecology. However, the, albeit limited studies that have been done on the Hirsel, point to the role of fringing macrophytes in silica cycling as a topic worthy of attention; reeds and grasses are known to contain large amounts of silica (Good, Whigham and Simpson 1978).

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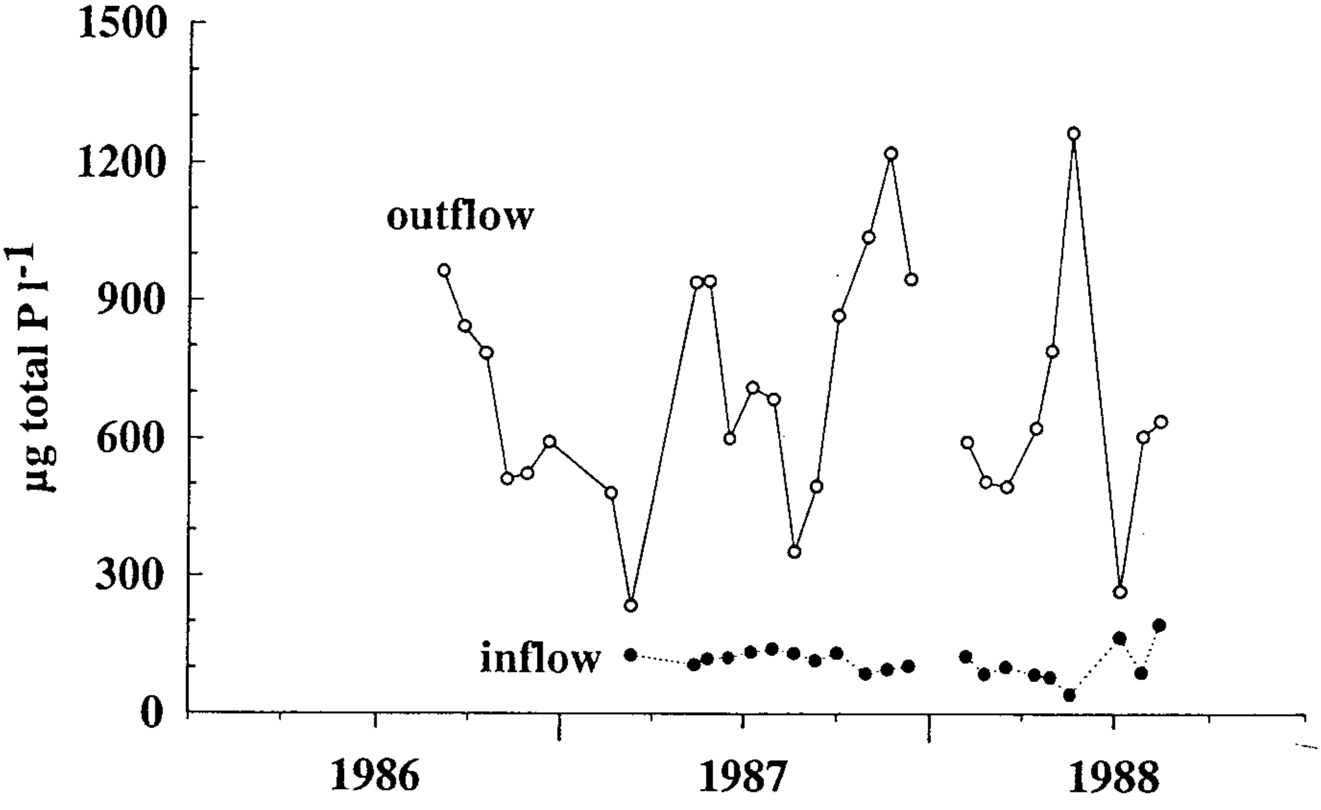
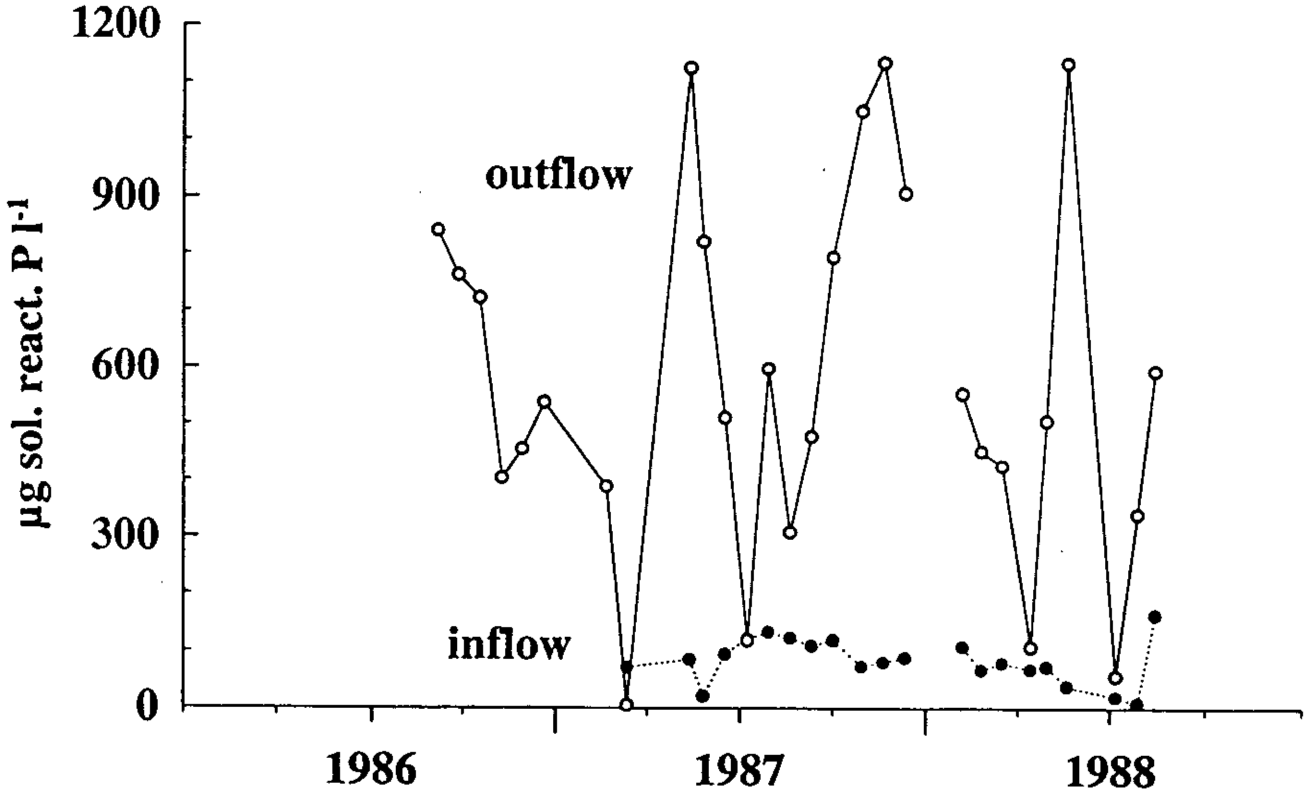
FIGURES

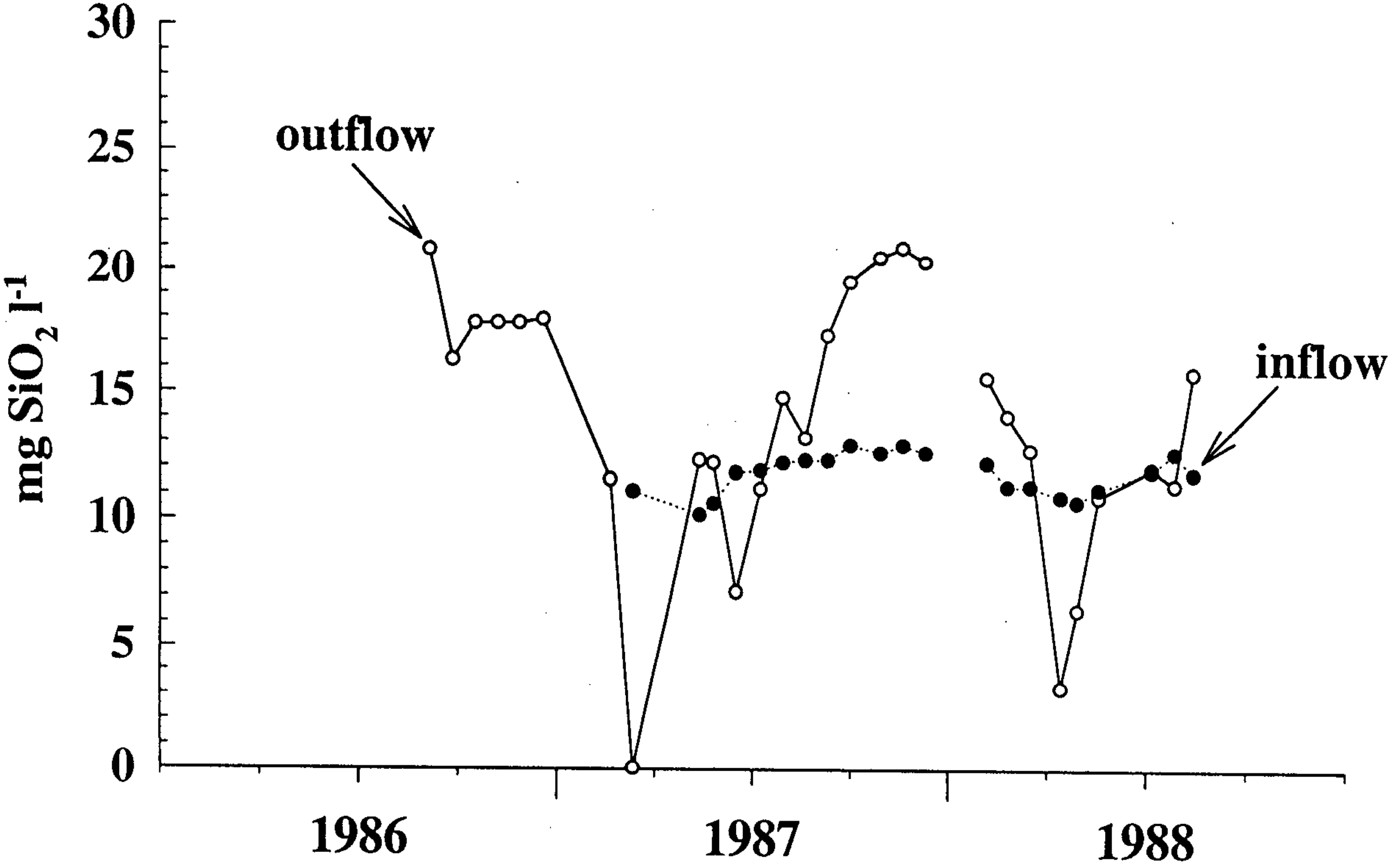
Total P levels in the Hirsel Loch



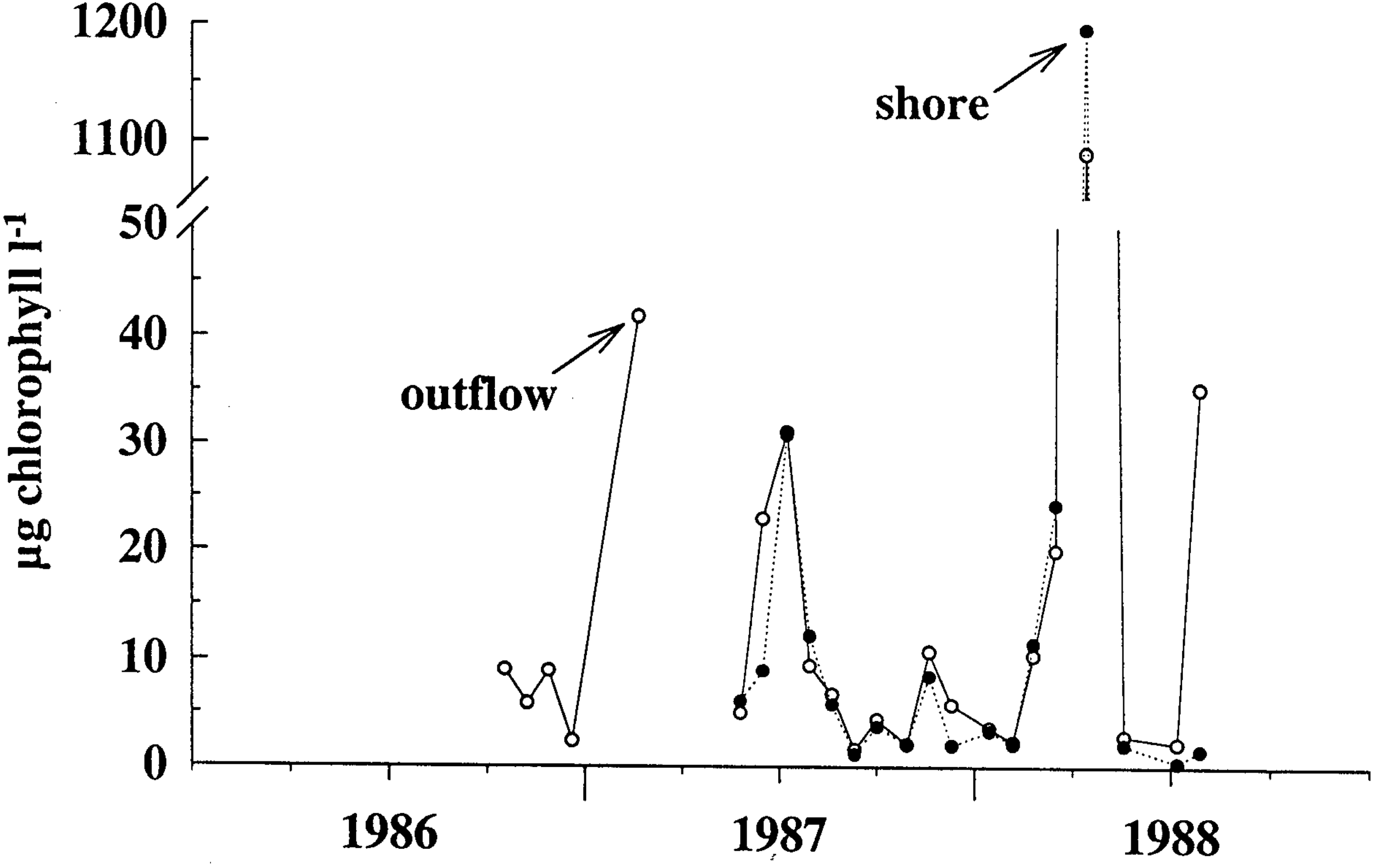
Soluble reactive P levels in the Hirsel Loch

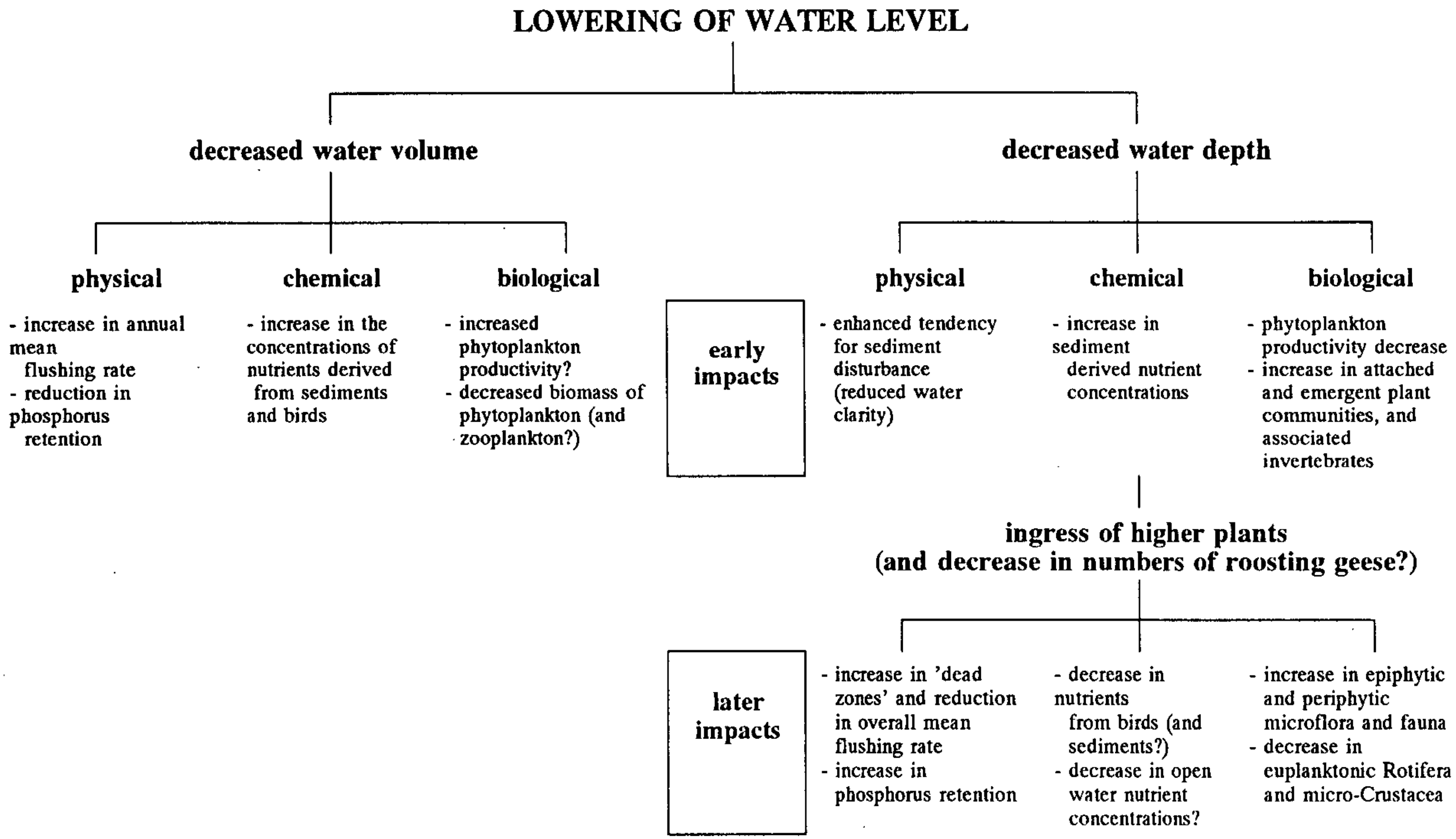


Dissolved silica levels in the Hirsel



Phytoplankton biomass (chlorophyll) in the Hirsel




LOWERING OF WATER LEVEL
decreased water volume
decreased water depth
physical
- increase in annual mean flushing rate
- reduction in phosphorus retention
chemical
- increase in the concentrations of nutrients derived from sediments and birds
biological
- increased phytoplankton productivity?
- decreased biomass of phytoplankton (and zooplankton?)
early impacts
physical
- enhanced tendency for sediment disturbance (reduced water clarity)
chemical
- increase in sediment derived nutrient concentrations
biological
- phytoplankton productivity decrease
- increase in attached and emergent plant communities, and associated invertebrates
ingress of higher plants (and decrease in numbers of roosting geese?)
later impacts
- increase in 'dead zones' and reduction in overall mean flushing rate
- increase in phosphorus retention
- decrease in nutrients from birds (and sediments?)
- decrease in open water nutrient concentrations?
- increase in epiphytic and periphytic microflora and fauna
- decrease in euplanktonic Rotifera and micro-Crustacea