Long-term Variation in the Stability of the Meromictic Lake Nordbytjernet Caused by Groundwater Fluctuations

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A zone with permanent anoxic conditions prevailed in the deep waters of Nordbytjernet before 1978 due to a significant depth gradient in dissolved substances. High concentrations of manganese and bicarbonate in the deep waters were most important for the lake's stability. The electrolyte concentrations in the mixed layer increased between 1978 and 1991, wiping out the depth gradient. A subsequent study showed a major variation in the solute concentration in the most important surface tributary that depends on fluctuations in the elevation of the groundwater table. A rising groundwater table seems to enhance oxidation of iron sulphides and dissolution of carbonates. Increasing solute concentrations in the mixed zone contributes to a weakening of the density gradient and reduced stability. Mineralised stream water may also intrude into the anoxic zone when the lake is not thermally stratified and cause precipitation of iron and manganese. Thus, a temporary rise of the groundwater table seems to be the reason why the lake changed from meromixis to holomixis. Lately the stream water concentrations have decreased and the lake has returned to meromixis. This periodic shift may be normal for this kind of lake.

Introduction

Nordbytjernet is a kettle lake in the Upper Romerike area in the central part of south-eastern Norway. Since 1967 it has been known that the deep waters of the lake contained a permanent layer of anoxic water with elevated solute concentrations.

Reduced forms of iron and manganese contributed to a density stratification that prevented total mixing during the seasonal turnover periods. Extensive limological studies were done during the period 1970-1978 (Hongve 1974, 1980, 1994, 1997). The type of meromixis can be classified as endogenic (type IV, *sensu* Walker and Likens 1975) caused by the shelter provided by a small and relatively deep basin, climatic conditions that cause little wind stress and biological processes in the deep waters. In the early work by Findenegg (1937) this type of lake was said to be meromictic for dynamic reasons. The transfer of kinetic energy through the surface being insufficient to prevail over biogenic processes that sustain concentration gradients in the depth. In Nordbytjernet dynamic equilibria between reduction and oxidation in the depth caused short residence times for dissolved iron and manganese (Hongve 1997). Any change in external conditions that enhanced the impact of oxygen in the deep waters might, therefore, reduce the strength of the density gradient and, perhaps, turn the lake from meromixis to holomixis.

In 1991 a significant change in chemical conditions was observed and the sampling of the lake was resumed. The whole water column was well mixed and the concentrations of calcium, sulphate, sodium and chloride had increased compared with the previous observations. The objective for the continued investigation was to see if the lake had attained holomixis on a permanent basis. If meromixis should become reestablished, it might provide insight into the processes that cause this condition.

It may be hypothesised that the changes in water chemistry and mixing conditions are consequences of anthropogeneous impact since the extension of urbanised areas in the catchment has increased significantly during the last decades. This may have altered hydrological pathways and the chemistry of the runoff. However, natural processes in the catchment may also have caused the changes in the lake. Fluctuations that most probably are natural, both in the groundwater table and the concentrations of electrolytes in the main surface tributary, support the latter view. The continued study of the lake shows that most of the changes in 1991 were temporary. The objective of this article is to present relationships concerning: i) meteorology and surface hydrology, ii) groundwater fluctuations, iii) transport of solutes from the catchment, and iv) concentration gradients in the lake, and to discuss the possible causal relations between these phenomena and the mixing conditions in the lake.

Material and Methods

Lake characteristics, hydrology and climate: The lake is situated in Quaternary glaciofluvial deposits in the Upper Romerike area, about 40 km northeast of Oslo, Norway (Fig. 1). The surface area is 0.28 km^2, mean depth is 9.9 m and maximum depth 23 m. Fig. 2 shows the bathygraphic curve for the lake basin. The theoretical water renewal time was measured in 1977 to be 1.4 years. That year around 40 per cent of
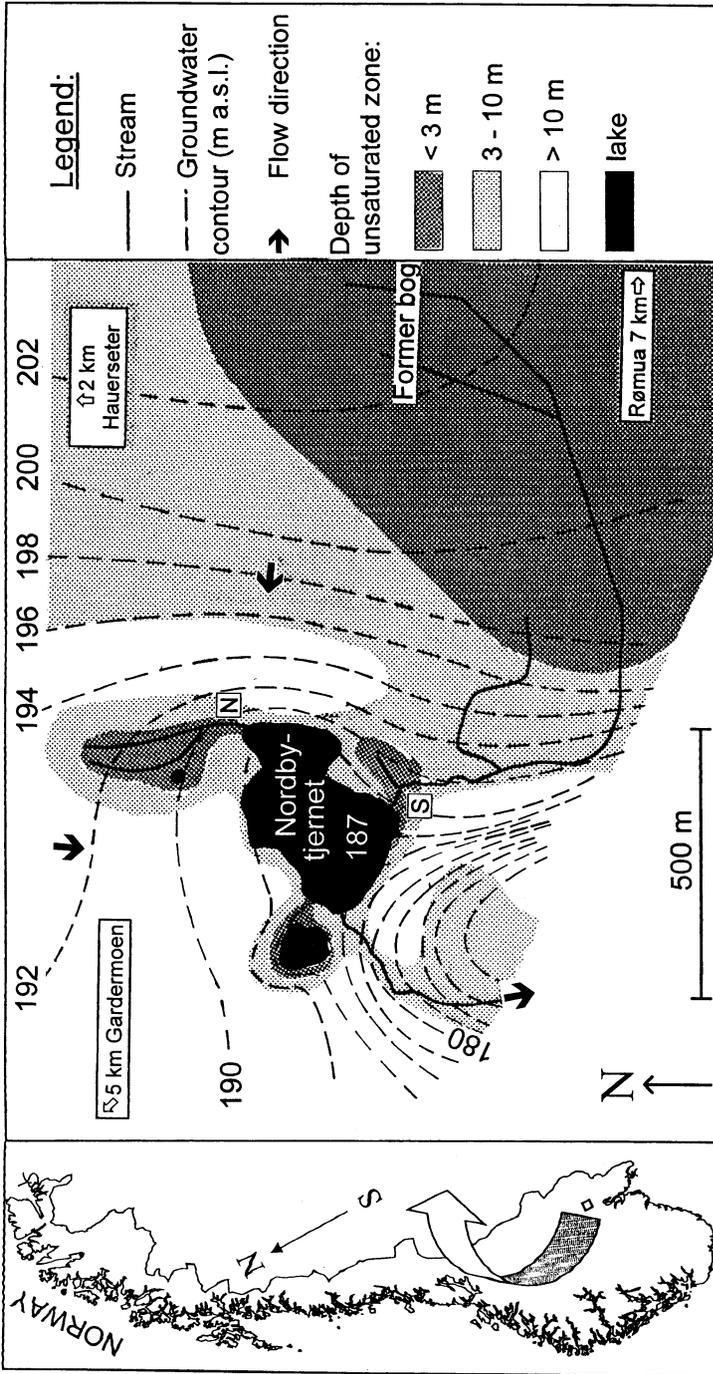
Fig. 1. The location of Nordbytjernet. The groundwater contour lines are drawn from Østmo (1976).
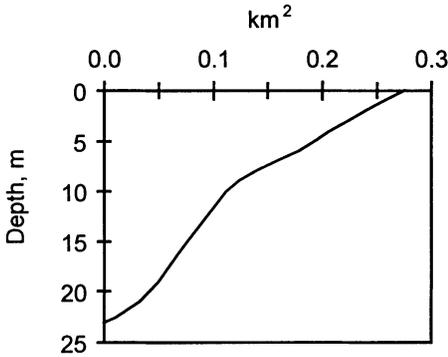
Fig. 2. The bathygraphical curve for Nordbytjernet

the annual hydraulic load came from the stream from the south (Stream S), 6 per cent from the small stream from the north (Stream N) while near 50 per cent entered as groundwater seepage directly into the lake. The chemical features of the lake depend on a rich supply of solutes that originate from chemical weathering in the Quaternary deposits that surround the lake. The load of iron is assumed to originate from oxidation of pyrites in these deposits (Hongve 1997). Ferrous/ferric ions and sulphuric acid are the primary products of the oxidation. The sulphuric acid weathers other minerals, especially carbonates, and becomes neutralised in the soil (Jørgensen *et al* 1991).

Time series of hydrological data for the period under consideration are not available for the Nordbytjernet drainage area and data from the adjacent catchments Risa and Rømua have been used instead. The groundwater station at Hauerseter (catchment Risa, NVE station 2.713.8), 3 km north of the lake, provides an almost continuous record of the groundwater level since 1967 (Furmyr 1973). Since the Risa catchment is drained mostly by groundwater discharge, it shows only minor seasonal fluctuations in discharge rates. Discharge data suitable for characterisation of short-term variations in surface runoff are therefore taken from the Kauserud station in the River Rømua, 9 km to the southeast (NVE station 2.331.0). The three catchments cover approximately the same elevation range and have fairly similar topography. Therefore, it is assumed that local differences in climate are negligible. Climate records are from Gardermoen, 6 km to the northeast. The annual mean temperature is 4°C, monthly means are below the freezing point during November-March, and the warmest month is July with mean temperature 16 °C. Further details on the catchment are given in Falkenmark (1972) and Hongve (1980).

Field and laboratory methods: The methods used until 1978 have been described in previous papers (Hongve 1994, 1997). From 1991 the analytical work was done by automated methods (Technicon AutoAnalyzer II) for Cl^-, SO_4^{2-}, NO_3, NH_4^+, total P and dissolved organic carbon (DOC). Metals are analysed using a Perkin-Elmer Model 5100 atomic absorption spectrometer. Sediment traps were suspended at various depths centrally in the lake. The traps used in 1996 were the same as used in

24

1977 (Hongve 1994, 1997). One water sample from 1988 was collected by personnel from the local angling association and analysed by the Norwegian Institute for Nature Research (Pedersen *et al.* 1990).

Assessment of electrical conductivity, κ_{25}: Electrical conductivity values from 1974 to 1977 have been calculated using the concentrations of dissolved components and specific molar conductivities (Golterman and Clymo 1969) multiplied by an average activity coefficient. The numeric value of this coefficient, 0.85, was assessed as the mean ratio between measured conductivities and the unamended sums of conductivities for all electrolytes present in significant concentrations. The correlation coefficient for conductivities measured and calculated in this way was $r = 0.990$. Values measured as κ_{18} were recalculated to reference temperature 25°C (κ_{25}) according to ISO 7888 (International Organization for Standardization 1985).

Assessment of stability: Hutchinson (1937) defined "meromictic stability" as the minimum work required to render uniform a chemically stratified lake that is devoid of thermal stratification. Berger (1955) introduced the term "concentration stability" which is synonymous with "chemical stability" (Walker 1974) since it need not imply that all meromictic lakes are chemically stratified. The concentration stability values have been calculated by the method of Walker (1974) for one-metre increments. The mean density of each increment was estimated from a smoothed curve drawn between the sampling depths. The density of each water sample was assessed by the method described by Hongve (1980). The concentration stability is given as J/m^2. The unit for stability used in most early works, gcm/cm^2, corresponds to 0.98 J/m^2.

Results and Discussion

Groundwater Fluctuations

Hydrological data for the years 1967-1996 are shown graphically in Fig. 3. During this period the groundwater at Hauerseter exhibited a conspicuous long-term variation with several consecutive years of sinking and increasing water level. The highest levels occurred around 1967 and 1989. For the following discussion it is assumed that the major, long-term fluctuations in groundwater level at Hauerseter are also reflected in the Nordbytjernet catchment. Water level observations in seepage lakes suggest that these fluctuations have affected the whole aquifer in the Upper Romerike. The amplitude will, however, decrease with increasing proximity to Nordbytjernet due to artificial and natural surface drainage and a constant surface level in the lake.

Simple regression analysis shows that variations in the annual sum of precipitation can explain much of the observed changes in the groundwater level during a hydrological year. The best correlation is obtained when precipitation for the period 1 May-30 April is related to annual change in groundwater level by 1 October-30 Sep-
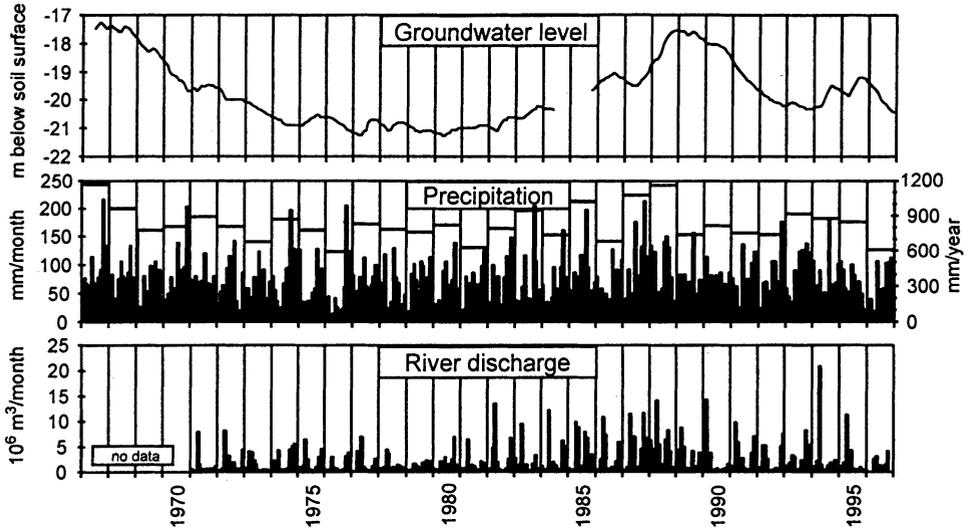
Fig. 3. Upper: Depth of the groundwater table below the soil surface level at Hauerseter for the period 1967-1996. Middel: Precipitation at Gardermoen; monthly sums as vertical columns and annual sums as horizontal bars. Lower: River discharge at Kauserud, monthly sums.

tember of consecutive years. This model explains 50% of the variation in the groundwater level. The remaining 50% may be explained by variations in the relative amounts of evaporation and discharge. Since no relevant records are available for these variables, surface discharge records from the Rømua catchment are used as a substitute variable in the further statistical treatment of the data. The discharge in Rømua during the cold season is positively correlated with the annual change in the groundwater level at Hauerseter. This is because both infiltration and surface discharge during the winter months depend on the same variables, such as the seasonal distribution of precipitation, the relative amounts of snow and rain and the duration of snow cover and melting episodes. Years with increasing groundwater level usually had a high flood in April (Fig. 3). When both annual precipitation and the surface discharge in April are taken into account in a multiple regression analysis they explain 71% of the variation in the groundwater level.

The Influent Stream Water

The electrical conductivity of the main influent stream (Stream S) has shown large variations during the study period (Fig. 4). The average value increased significantly from 1972 to 1976. The highest values were observed in 1991. Fig. 5 shows concentrations of various solutes. Calcium and sulphate caused most of the conductivity variation, but also potassium and magnesium have shown similar variations in a lower concentration range. Sodium and chloride have increased significantly since
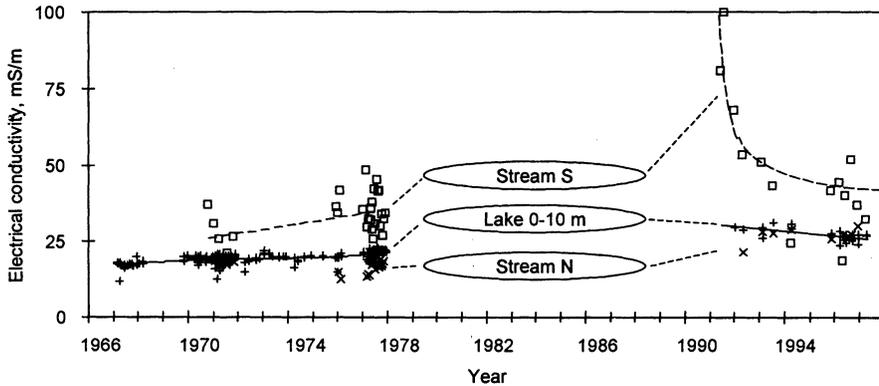
26

Fig. 4. Electrical conductivity values, mS/m (κ_{25}) in samples from the lake and two surface tributaries. ×: Stream N (without regression lines due to few observations), +: Nordbytjernet, 0-10 m layer. A third order regression line is inserted for the period 1967 – 1977 and a linear regression line for 1991-1997. □: Stream S. A linear regression line is inserted for the years 1970-1977 and a visually adapted graph for 1991-1996. The two lower values (from 1994 and 1996) were measured during snowmelt floods and have been disregarded.

the 1970s, but contrary to the former components, they have not decreased after 1991. Iron and manganese in the influent stream have followed the same pattern as sulphate. The supply of iron was mostly in the form of suspended ferric hydroxide while manganese was supplied as dissolved species (Hongve 1997). Another source of water renewal was groundwater seepage through the sandy bottom in the littoral. Due to sampling problems the concentrations of solute ions in the seepage water have not been measured regularly, but former measurements have shown that both this water and the small northern stream (Stream N) were not significantly different from the lake's mixed layer (Hongve 1994).

Integrated hydrological and hydrochemical models have been used with success to model chemical water quality in aquifers that show seasonal fluctuations. During wet conditions a large proportion of the water moves superficially in the soil, while dry conditions are dominated by water passing through deeper soil layers. High groundwater levels coincide, therefore, with a discharge that is low in dissolved electrolytes (Sandén *et al.* 1991). The water chemistry in the catchment of Nordbytjernet is obviously influenced by other processes since it shows the opposite relationship with the groundwater level. These processes are yet not fully understood, but the results seem to confirm the assumption that the high load of iron and other dissolved minerals originates from oxidation of pyrites in the Quaternary deposits. Jørgensen *et al.* (1991) found 0.4-0.7 per cent pyrites in unweathered soil samples. There may be a local, more concentrated deposition of pyrites around Nordbytjernet, since this lake has higher sulphate concentrations than the neighbouring kettle lakes
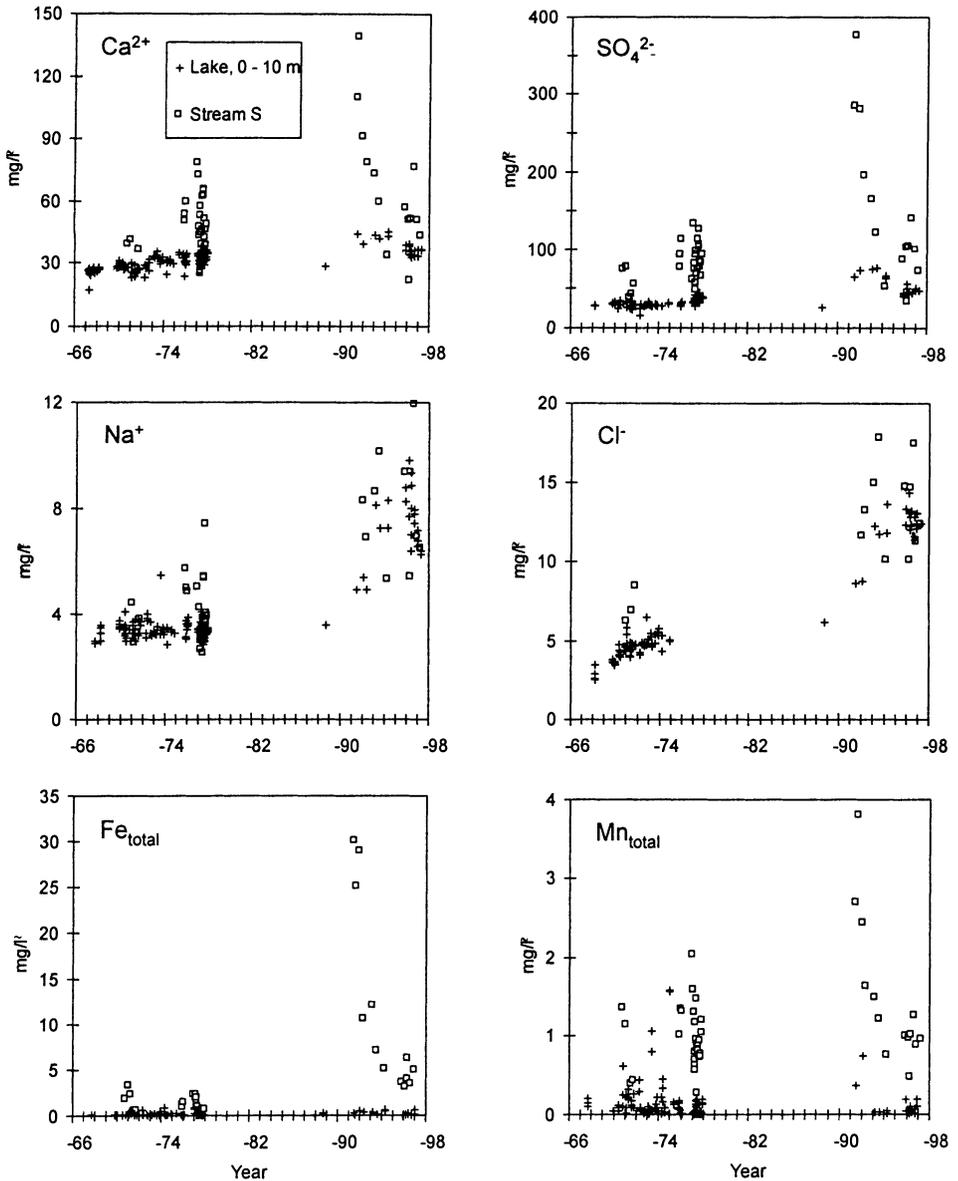
27

Fig. 5. Concentrations of some important components in the main surface tributary, Stream S, and in the mixed zone (0-10 m) of the lake.

(Hongve 1977). Artificial drainage might impel pyrite oxidation. The reaction is microbially mediated and enhanced by alternating wet and dry conditions (Matthes 1982). It may, therefore, be sustained by fluctuations of the groundwater level.

The variation in groundwater level and stream water chemistry during the latest

28

study period suggests a strong relationship between weathering processes in the ground and groundwater fluctuations. The chemical variation may not be directly coupled with variation in the oxidation rate since products of chemical weathering may temporarily accumulate in the soil profile. The aqueous concentrations may, therefore, respond quicker to changes in hydraulic flushing than to altered reaction rates. It is also possible that amorphous ferrous sulphide, which is more susceptible to oxidation than pyrite, can be deposited in reducing compartments of the soil and become oxidised when the soil environment is altered (Per Jørgensen, Agricultural University of Norway, personal communication). The highest concentrations of iron in the stream water were accompanied by high sulphate concentrations, as should be expected if the source was oxidised iron sulphides. Increased chemical weathering due to formation of sulphuric acid was probably the reason potassium and magnesium followed the same pattern of variation as iron and sulphate. The concentrations of iron and sulphate reached much higher concentrations in Stream S than in Stream N. This complies with the assumption that the groundwater fluctuations were higher at some distance from the lake than in the influence area of the Stream N, closer to the lake (Fig. 1).

Linear regressions show that the electrical conductivity and the major ionic constituents in Stream S, except sodium and chloride, correlate positively with the groundwater level. The levels of statistical significance for these relations are notably improved if the time needed for horizontal displacement of the groundwater between the area of weathering and the sampling point in the stream is taken into account. More detailed hydrogeological information would be required to assess the average travelling distance and the speed of the groundwater flow. However, when plots are made of chemical concentrations in stream water versus groundwater level, the best correlations are obtained using delay periods of two years between the respective readings (Fig. 6). This gives correlation coefficients $r \geq 0.9$ between groundwater level and concentrations of sulphate, total iron (log value), manganese, calcium and magnesium, and $r = 0.9$ for alkalinity.
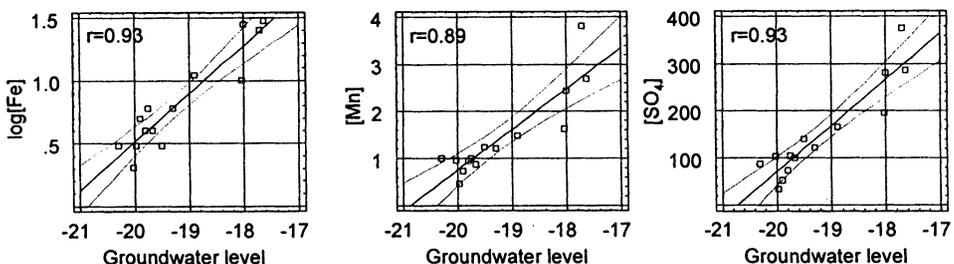

Fig. 6. Solute concentrations as mg/l in Stream S versus elevation of the groundwater table at Hauerseter two years earlier, as metres below the soil surface. The regression lines with 95% confidence intervals are shown for each parameter.

29

The variation pattern for sodium and chloride differ from the other ionic components and this may have anthropogeneous reasons. Increasing use of salt for de-icing of roads is assumed to be the reason that sodium chloride concentrations have increased in other lakes with urbanised catchments in South Norway (Kjensmo 1997). It is also the most probable reason for the increasing concentrations in the catchment of Nordbytjernet.

The Mixed Layer

The concentrations of solutes in the mixed layer of the lake varied according to the variable supply from Stream S (Figs. 4 and 5). The concentrations in the lake increased during periods when the stream water was much more concentrated than the lake water, and declined when the average supply was less concentrated. The observation from the mixed layer in 1988 suggests that the major increase took place between 1988 and 1991.

It may be discussed to what extent the chemical variations in the lake have also been influenced by seepage of more mineralised groundwater in the deeper waters. However, the following evidence indicates that this has not been significant: i) The variations in solute concentrations in the lake may be connected with changes in the groundwater level more than with the groundwater level *per se*. If a high groundwater level causes inflow of mineralised groundwater directly to the deep waters, this should have occurred by the end of the 1960s when the electrolyte concentration in the lake was moderate. The duration of this period with high groundwater level is unknown. ii) Groundwater monitoring in the area has not revealed major changes or spatial differences that show that the deeper part of the aquifer has been subject to similar chemical changes as the stream water (Martinsen 1993; Sørlie and Høysæter 1994). iii): Surface drainage controls the groundwater level near the lake and ensures a relatively constant groundwater pressure. The hydraulic conductivity of the deposits is generally highest near the surface where they consist of glaciofluvial gravel and sand while the deeper layers consist of less permeable silty glaciomarine deposits (Jørgensen and Østmo 1990). Therefore, it seems unlikely that inflow of groundwater in the deeper waters should be subject to variations caused by variation in the groundwater pressure at a distance.

The Deep Waters

The solute concentrations in the stagnant part of the lake (monimolimnion) increased during the 1970s (Fig. 7) and the concentration gradient gradually became steeper. However, by 1991 the solute gradient in the water column was almost wiped out, although iron, manganese and bicarbonate have subsequently increased again. However, they are still well below their respective concentrations in the former meromictic period. The other major cationic constituents (Ca, Mg, Na and K) have in-
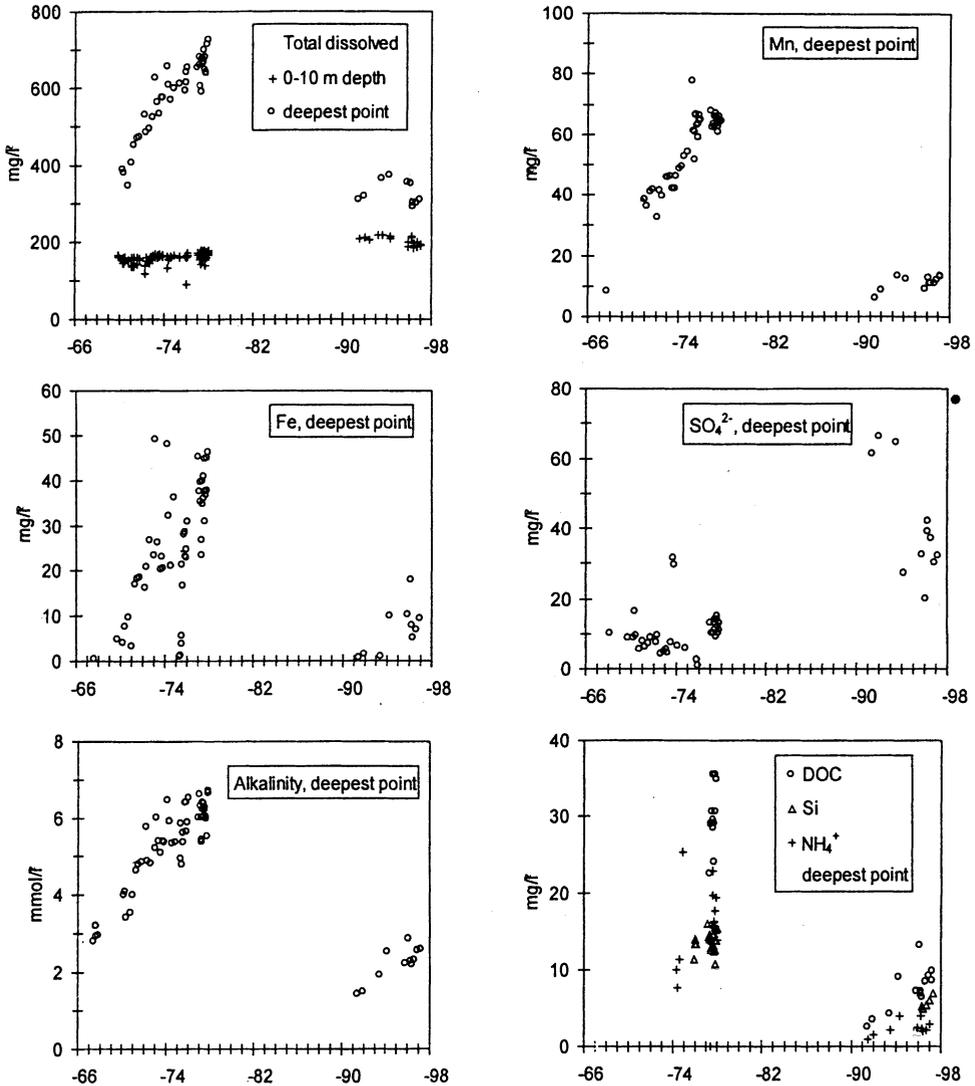
30

Fig. 7. Upper left: Concentrations of total dissolved substances in samples from the mixed layer and from the deepest point in Nordbytjernet. Other diagrams: Concentrations of various components at the deepest point of the lake up to 1977 and for the period 1991-1996.

creased their overall concentrations after 1977. Sulphate was previously at lower concentrations in the anoxic zone than in the mixed layer but in 1991 it was homogeneously distributed and the concentration was twice what it used to be in the mixed layer. A homogeneous distribution of sulphate has prevailed since then.

31

The abrupt change in solute concentrations in the deep waters may be a result of increased transfer of kinetic energy through the surface due to climatic changes or local conditions. Growth and clear-cutting of forest in the closest vicinities of small lakes are examples of external circumstances that can influence mixing conditions (Culver 1975, 1977). However, since other lakes in the area with less concentration stability than Nordbytjernet have remained meromictic during the same span of time, and no local change has increased the wind impact, this is not a likely explanation. It is, therefore, more probable that the concentration stability has been weakened due to changes in chemical loading. The endogenic processes that cause internal loading of reduced substances should not be liable to a sudden change under otherwise stable conditions and the most probable explanation of the conclusion of meromixis between 1978 and 1991 is, therefore, the observed change in external loading. Increased concentrations of solutes in the stream water may affect the concentration stability in two ways: First, the stream water becomes mixed with epilimnic water during the summer when the temperature is decisive for the water density. This results in a weaker density gradient and reduced power to withstand full circulation when the lake is without thermal stratification. Secondly, stream water with high solute concentrations may intrude into layers of the anoxic monimolimnion with corresponding density during the cold season. Oxygen from the stream reacts then with reduced lake water components and initiates precipitation of oxides of iron and manganese. The precipitates formed in this way will be highly sorptive and will probably also remove other ionic substances and dissolved organic matter from solution.

The intrusion depths for water from Stream S have been assessed for all winter observations provided sufficient chemical data were available to assess a density gradient for the water column (Fig. 8). Suspended matter has usually been in minor concentrations (Hongve 1997) and has been disregarded in the calculation. However, high concentrations of ferric hydroxides in the stream in 1991 have probably given significant extra contributions to the gross density of this water and increased the chance that it would reach the deepest point of the lake. Up to 1977 the calculated intrusion depth for stream water was between 17 m and 20 m. In 1991 the high solute concentrations in the stream corresponded to the deepest point in the lake. By the end of 1996 the assessed intrusion depth was reduced to *circa* 18 m. Intrusion of cold stream water during winter time is the most probable reason of an anomaly in the temperature stratification in the lake during the meromictic period in the 1970s. Usually the temperature curve showed a minimum of 3.6°C between 10 and 15 m depths (Hongve 1974, 1997). Given this notable influence on the temperature distribution, it seems very likely that chemical effects would occur if the intrusion took place in the restricted volume of anoxic water at greater depths.

The temporal variation in total dissolved solids at maximum depth (Fig. 7) was mainly caused by the redox sensitive components Fe^{2+} and Mn^{2+}, with bicarbonate acting as a labile counterion. Different depth profiles for iron and manganese reflect
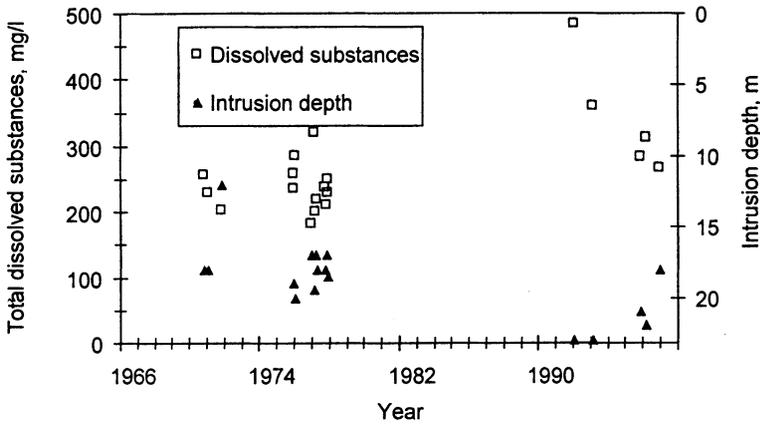
Fig. 8. Total concentrations of solutes in Stream S and assessed intrusion depths in the lake on sampling occasions without significant thermal stratification.

their particular redox properties. Dissolved reduced manganese may exist in thermodynamic equilibrium with dissolved oxygen although it will normally be exhausted after some time by microbially mediated oxidation and precipitation (Stumm and Morgan 1995). It was usually present in significant dissolved concentrations in oxygenated water during partial turnover events (Hongve 1997). Reduced manganese in the anoxic zone might be controlled by carbonate precipitation as rhodochrosite (Hongve 1997). High concentrations of dissolved iron were only found close to the sediment interface at the maximum depth and under strictly anoxic conditions, controlled by oxidation due to redox coupling with settling manganese oxide and some sulphide precipitation (Hongve 1997). In the autumn of 1977 the total inventories amounted to 6,700 kg Mn and 1,100 kg Fe. In the autumn of 1996, when the maximum concentrations were less than 20 per cent of those in 1977, the inventories were, nevertheless, as high as 4,000 kg Mn and 1,200 kg Fe. The concentrations in the deepest part of the water column were accordingly unimportant for the total inventories because of the limited horizontal extension of this layer (Fig. 2).

Other components were also accumulated in the depth of the lake and showed variable concentrations in harmony with the changing circulatory pattern. Ammonia, silica and DOC occurred in concentrations so high that they could be important for the concentration stability of the lake (Fig. 7). These concentrations were probably secondary long-term effects of the stagnation, since they originate from mineralisation of biogenic matter and desorption from settling hydrous oxides of iron and manganese. After 1991 these components have again shown increasing concentrations. Sulphate used to have an inverse gradient due to anaerobic reduction in the deep waters. After 1991 sulphate has been homogeneously distributed in the lake.

33

Table 1 – Average sedimentation rates in Nordbytjernet from ultimo March to medio June for the years 1977 and 1996 measured in suspended sediment traps. All values are expressed as mg/m^2/day.

Year	1977	1977	1996	1996
Depth	10 m	19 m	10 m	19 m
Total catch	556	596	788	751
Loss on ignition	206	205	232	211
Fe	74	76	78	109
Mn	16	20	21	5
P	2.2	2.1	1.6	1.3

Sediment Processes in the Depth

A comparison of sediment trap catches from spring and early summer in 1977 and 1996 is shown in Table 1. The total sedimentation rate was higher in 1996 but the sedimentation of organic components and iron and manganese in the mixed layer were on the same level as earlier. In 1996 the catches of iron and manganese differed between 10 m and 19 m. The sedimentation rate increased with depth for iron while there was a corresponding decrease for manganese.

Despite the reduced concentration stability the anoxic zone has recently extended higher than during the 1970s. In 1977 the sediment trap suspended at 19 m depth was in the lower part of the oxic zone and the composition of settling sediments was not significantly altered between 10 m and 19 m depths. In spring 1996 the 19 m trap was in an anoxic environment and the change in conditions between the traps were reflected in a variance in sediment composition. The decrease in sedimentation rates with depth for manganese and the increase for iron was most probably due to coupling of manganese reduction and iron oxidation in the anoxic zone. Similar redox coupling was observed in 1977, but usually it took place deeper in the lake (Hongve 1997). The sediment records suggest that the total loads of iron and manganese were at almost equal levels in 1977 and 1996. The higher total sediment load in 1996 can probably be ascribed to soil erosion that can be highly variable due to both anthropogeneous and natural circumstances.

Stability

The concentration stability of the lake has been assessed for all sampling dates for which sufficient data are available (Fig. 9). For the period 1970-77 the stability ranged between 10 and 20 J/m^2, with a temporary decline during the cold season in some years. The stability was significantly lowered during 1991 – 1993 and was obviously too low to prevent events of total mixing during the seasonal turnover periods. After 1993 the stability has again been increased and it looks as if the accumulation of solutes in the deeper waters has been sufficient to prevent complete mixing since then. In 1997 the stability was at the same level as around 1970.
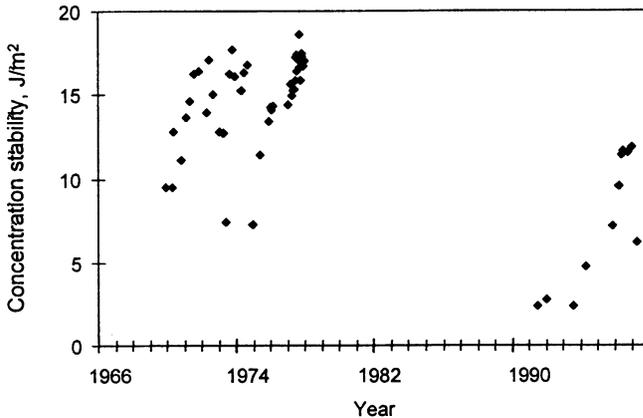
34

Fig. 9. Calculated concentration stability values for each sampling occasion.

It appears from the calculations of concentration stability that solutes in the deepest part of the lake, in spite of steep concentration gradients, had little influence on the stability. In average the solutes in the deepest one metre layer were responsible for only 4% of the total concentration stability during the meromictic periods. Due to the limited horizontal extension this layer had a limited influence on the position of the lake's centre of gravity. In contrast the layer between 18 and 22 m was responsible for around 80% of the concentration stability.

The redox sensitivity of the concentration gradient is most probably important for the temporary loss of stability. By the introduction of oxygen, iron and manganese form precipitates that settle to the bottom rather than become homogeneously distributed within the water column. Theoretically, no mechanical work is needed to elevate the point of gravity for the inventories of iron and manganese since they can be reduced to nil if mixing proceeds very slowly, or if oxygen by some means, is introduced directly into the stagnant layer. The stability is then reduced further because bicarbonate is converted to free CO_2 in quantities equivalent to the oxidised amount of iron and manganese. The contribution from the labile solutes ($Fe(II)$, $Mn(II)$ and the fraction of HCO_3^- transformed to CO_2) was around 30-40 per cent of the total concentration stability during 1974-1977. Most of the concentration stability in Nordbytjernet, around 60%, was due to the depth gradient in total CO_2 (free CO_2 plus carbonates) which is released from anaerobic decomposition of organic materials in the monimolimnion or the lake bottom.

Conclusion

The present study has shown that endogenic meromixis may be an unstable condition for a lake, even after several years with stagnation and accumulation of solutes in the depth. Weak concentration stability may be wiped out because of events in the

35

catchment. A case is described where groundwater fluctuations have led to increasing mineralisation of the main influent stream. The shift from meromixis to holomixis is most probably due both to increasing water density in the mixolimnion and intrusion of oxygenated stream water into the monimolimnion. After partial restoration of the external loading meromictic conditions were reestablished, and the new-formed density gradient appears to be stable under the ambient conditions. Carbon dioxide released from decomposition of organic matter was most important for the density gradient that restrained full circulation. During the prolonged stagnation period other products of organic decomposition also built up in the anoxic layer and increased the concentration stability. The observed variations in water chemistry and mixing conditions in Nordbytjernet appear to be consequences of natural hydrological processes in the catchment, while anthropogeneous influences are of minor importance. However, a continued increase in the concentration of road salt in the tributaries may also reduce the meromictic stability. If the lake can be protected from anthropogeneous impact in the future, the mixing conditions may depend on shifts in groundwater level in the catchment. Shifts between meromixis in dry periods and holomixis when consecutive years with high precipitation build up a high groundwater level may be normal for this lake.

Acknowledgements

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38