

The Norwegian groundwater monitoring network (LGN): alkalinity trends in selected aquifers from southern Norway during 1980-1990

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Introduction

In 1977, the Geological Survey of Norway (NGU) and the Norwegian Water Resources and Energy Administration (NVE) initiated a Nation-Wide Groundwater Network (Landsomfattende grunnvannnett, LGN) to co-ordinate the collection of groundwater data in Norway. This network was extended in 1980 by including four stations within or close to 'calibrated' catchments, in order for the Norwegian Institute for Water Research (NIVA) to carry out, in co-operation with NGU, its responsibility for groundwater monitoring within the context of the Norwegian

Monitoring Programme for Long-Range Transported Air Pollutants. This programme is a major, collaborative initiative co-ordinated by the State Pollution Control Authority (SFT) to describe and follow trends in precipitation chemistry, soil and water acidification, and ensuing damage to fish and invertebrates.

Presently, after a minor gradual downsizing, LGN consists of 38 monitoring stations distributed all over the country (Fig. 1). Groundwater level is measured 2-4 times/month at each station, groundwater temperature is monitored 2-4 times/month at 31 stations, and groundwater chemistry is determined 1-2 times/year at 17 stations and monthly at the four SFT stations (Birkenes [station 2], Åmli [3], Evje [48] and Langvassli [21]). The purpose of the present communication is to illustrate how the data from the Norwegian groundwater monitoring network, in this case alkalinity values, can be used.

Methods

The analytical programme of LGN comprises the determination of pH, turbidity, electrical conductivity, Ca^{2+} , Mg^{2+} , Na^{+} , K^{+} , Cl^{-} , SO_4^{2-} , NO_3^{-} , alkalinity (HCO_3^{-}), SiO_2 , Al (labile, nonlabile and reactive fractions) and organic material (permanganate number); Fe^{2+} and Mn^{2+} were only analysed for up to 1982-1983. Up to 1990, the groundwater chemistry was determined at NIVA, where alkalinity was determined on the basis of an acid-titration to pH 4.5 and corrected to the 'equivalence alkalinity' using a standard formula. Analysis of all LGN samples, except those from the four SFT stations, was transferred to NGU in 1991, where cations are determined by ICP-ES and anions by HPIC. This change in analytical laboratory produces a noticeable break in the time-series of some elements/stations.

Results

A database containing in excess of 1000 water analyses has been assembled so far. Annual reports outlining each year's main findings have been produced both for the LGN Project (e.g.,



Fig. 1. Location of LGN monitoring stations in Norway. Stations selected for the present discussion are underlined once (Group I), twice (Group II), or three times (Group III) (see text).

Kirkhusmo 1993) and for the SFT Programme (e.g., SFT 1993). The data currently is being re-analysed with the aims of describing and interpreting the major trends. To this effect, overall, long-term time-series and detailed, year-by-year time-series for the various parameters are plotted and analysed. Additionally, between-year and between-month variations are displayed using boxplot diagrams where sufficient data are available. Finally, covariations between measured parameters are examined visually and treated statistically. Some well-defined trends are readily apparent in many cases, especially for the four SFT stations with monthly chemical determinations. For many of the other stations, the sampling frequency of ca. 2 samples/year can yield somewhat unclear patterns at this stage.

Discussion

Groundwater acidification has been found to gain momentum in the 1990's at Birkenes, southern-most Norway, as based on pH, alkalinity, acidity,

acid neutralising capacity, hardness/alkalinity ratio, and other trends (Caritat, 1995). Here, we investigate whether or not there is a clear pattern of groundwater acidification on a regional scale in southern Norway. We selected 12 stations, starting from the southern tip of the country and moving northward, based on the criterion that there had to be sufficient data points collected (we arbitrarily set the lower limit at ten). Most of the 12 selected stations (10 wells and 2 springs) are located in glacial deposits developed upon acid-sensitive bedrock (e.g., see map in Brömssen 1989). None of the stations are coastal, and they have a more or less similar climate, in very general terms. Additionally, the stations can be roughly divided into three groups according to the total deposition of sulphur reported for the area (see map reproduced in Eriksson et al. 1992): Group I, where the total deposition of sulphur is <40 meq/m² (stations 14, 52, 24 and 4); Group II, where it is 40-60 meq/m² (stations 5, 51, 10 and 15); and Group III, where it is >60 meq/m² (stations 9, 11, 43 and 13).

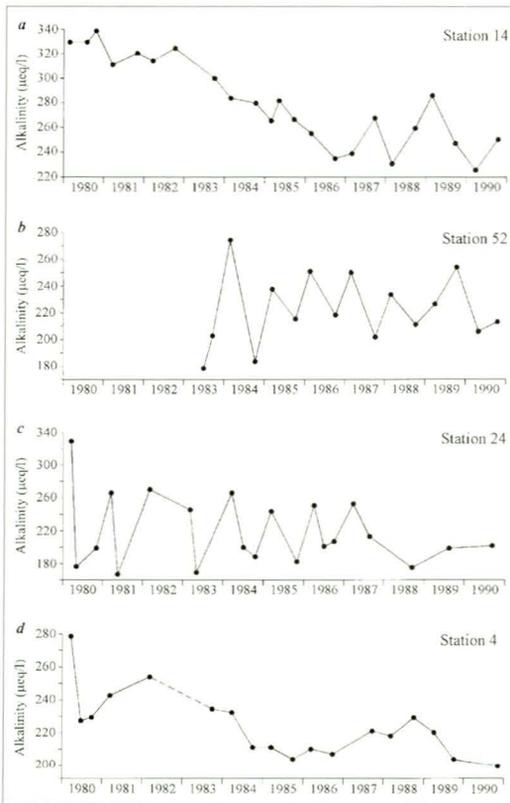


Fig. 2. Alkalinity (µeq/l) time-series for Group I LGN stations 14 (a), 52 (b), 24 (c) and 4 (d).

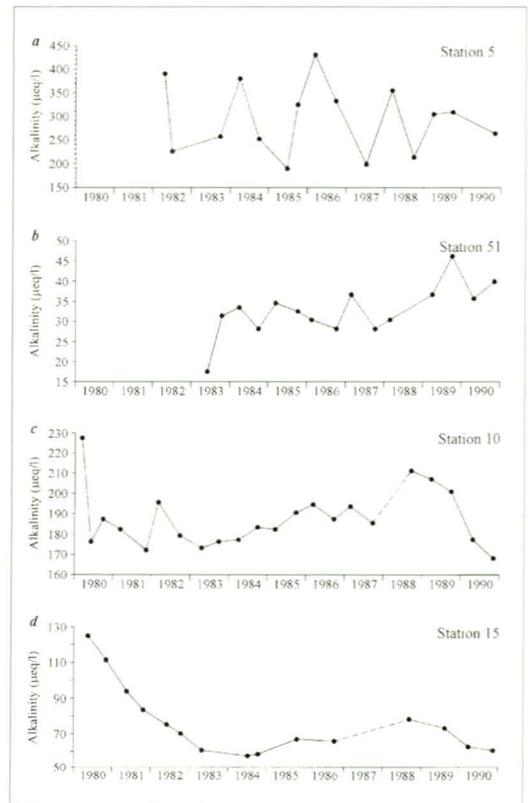


Fig. 3. Alkalinity (µeq/l) time-series for Group II LGN stations 5 (a), 51 (b), 10 (c) and 15 (d).

Here, only one important acidification index, namely the alkalinity trend (Figs. 2-4), is considered and this for the period 1980-1990. Where groundwater acidification has occurred, or is occurring, a drop in alkalinity should be observed, and this is usually considered to be a much more reliable indicator than a pH drop because of the pH dependence on $p\text{CO}_2$ (e.g., see Henriksen & Kirkhusmo 1986). We stress, however, that no exhaustive acidification study should rely on the trends shown by only one of the several index parameters, but this is done here for the purpose of gaining a rapid regional overview.

The alkalinity trends for the stations from Group I (Fig. 2) show that at least two of the stations (14 and 4) experienced a clear decrease over the 1980-1990 period (Figs. 2a,d). In the two other cases (stations 52 and 24, the latter being a spring), the alkalinity is relatively stable on a long time-scale, even if there are large variations between measurements (Figs. 2b,c). This variability between consecutive measurements at stations 52 and 24 most likely is caused by seasonal controls on the groundwater levels (or spring discharge rates): measurements made just before snowmelt when groundwater/discharge is low (early in the year) have higher alkalinities than those made in the autumn, when groundwater/discharge is high. This seasonal effect is also reflected in the conductivity values (not shown here), with higher conductivities recorded before snowmelt than in the autumn. There usually exists a strong positive correlation between alkalinity and conductivity, and a strong negative correlation between conductivity and groundwater level. Group I stations are all characterised by a relatively high groundwater alkalinity (>150 $\mu\text{eq/l}$).

Figure 3 shows the patterns for Group II. Station 5 (a spring) has had a very variable alkalinity, at least partly as a result of variations in seasonal discharge rates, with no clear overall upward or downward trend (Fig. 3a). At stations 51 and 10, the alkalinity has increased from 1983 to 1988/1989 (Figs. 3b,c), and in the latter case it began to drop from 1988 to 1990 (Fig. 3c). Station 15 shows the smoothest alkalinity time-series of all stations considered here, with a step decrease from 1980 to 1984, followed by a slow increase from 1984 to 1988, and, again, an alkalinity drop from 1988 to 1990 (Fig. 3d). Two of the stations (5 and 10) in Group II have relatively high alkalinities (>150 $\mu\text{eq/l}$), while a third (15) has a lower alkalinity (50-150 $\mu\text{eq/l}$), and the fourth one (51) has a very low, but apparently increasing, alkalinity (<50 $\mu\text{eq/l}$).

In Group III (Fig. 4), only one station (11) has a definite downward trend (Fig. 4b), despite this

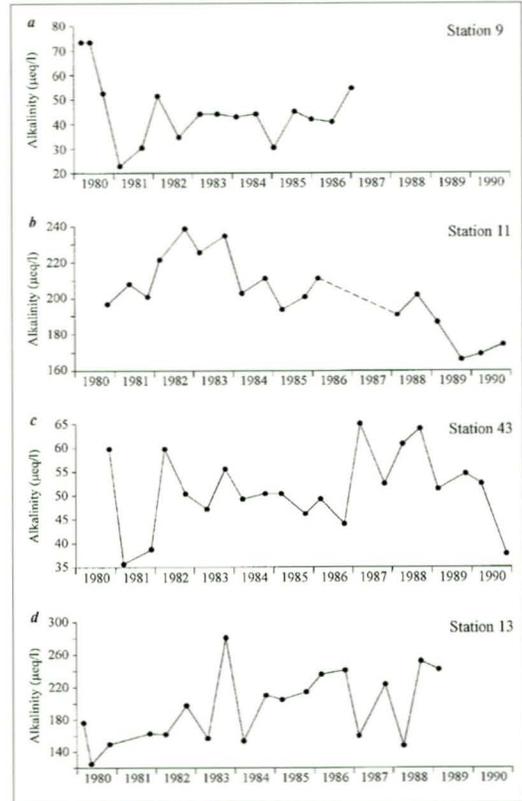


Fig. 4. Alkalinity ($\mu\text{eq/l}$) time-series for Group III LGN stations 9 (a), 11 (b), 43 (c) and 13 (d).

being the Group supposedly most affected by sulphur deposition. Even at station 11, the alkalinity level is relatively high (>150 $\mu\text{eq/l}$). The three other stations (9, 43 and 13) show no clear trends, due to a great variability between measurements and relatively few samples (Figs. 4a,c,d). At station 13, alkalinity is also relatively high (mostly >150 $\mu\text{eq/l}$). Only at stations 9 and 43 are the alkalinity levels relatively low (20-70 $\mu\text{eq/l}$).

Conclusions

The above discussion illustrates how data from the LGN Project can be used to analyse the past condition of aquifers around the country. It also shows that despite a selection of stations with very roughly similar geology and climate, but with different sulphur deposition loads, no clear relationship can be found between these loads and the aquifer's response in terms of alkalinity. Indeed, although evidence for decreasing alkalinity levels was found in four of the selected stations from southern Norway, there was a distinct

lack of correlation between the number of stations with a decline, or the magnitude of the decline itself, and the increasing sulphur deposition from Group I to Group III. This ambiguity highlights the need for detailed understanding of why a similar signal (a given rate of sulphur deposition, for instance) yields a very different response in (not so) different aquifers, or, even more fundamentally, of what controls these long-term alkalinity trends in addition to sulphur loading. Such understanding must be based upon careful investigation of geochemical and hydrological processes at the catchment scale (see Sæther et al. 1994).

The discussion of the alkalinity trends in selected stations from southern Norway illustrates a need for further investigations if we are to enhance our ability to understand the influence of natural processes in, and anthropogenic influences on, groundwater systems.

In general terms, LGN data can be used for the analysis of the variability, in time and in space, of groundwater level and composition resulting from natural, background processes (e.g., the natural influences of bedrock, drift and soil composition, of hydrogeological and hydrological conditions, and of seasons and climatic zones), from anthropogenic disturbances (e.g., the effects of changes in land-use, where these have occurred), and from large-scale or global processes (e.g., the role of acid deposition, environmental pollution and climate change). LGN provides a very valuable temporal and geographic information database about Norway's groundwater.

Acknowledgements

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