

## **Acidification of Groundwater in Norway**

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The chemistry of ground- and surface-water in areas of similar geologic settings are compared by plotting the equivalent concentrations of each component in an XY-diagram. The deviations of each chemical component from the line through origin and the plot of the two ionic sums (line of proportional composition) give information about the differences in composition of the two types of water.

If we assume that the geologic conditions of the ground- and surface-water are similar when the plots of calcium and magnesium will fall close to the ionic sum line, then we find that the alkalinity is relatively higher and the sulphate concentration is relatively lower in groundwater than in surface-water. These observations indicate that in areas influenced by acid precipitation the groundwater is acidified less than the surface water.

The groundwater stations studied so far show a regional tendency to lower pH-values in areas where regional lake surveys show low pH in surface waters, these areas include southernmost Norway and parts of eastern Norway.

### **Introduction**

The regional acidification of freshwaters in Scandinavia, Scotland and Northern America is now well-documented (Drabløs and Tollan 1980, Overrein et al. 1980) and is strongly connected to the increased acidity of precipitation.

Acid groundwaters have been reported in Sweden (Hultberg and Johansson 1981), especially in shallow wells and inflowing groundwater to lakes. In deeper groundwater reservoirs no significant decreases in pH have been observed

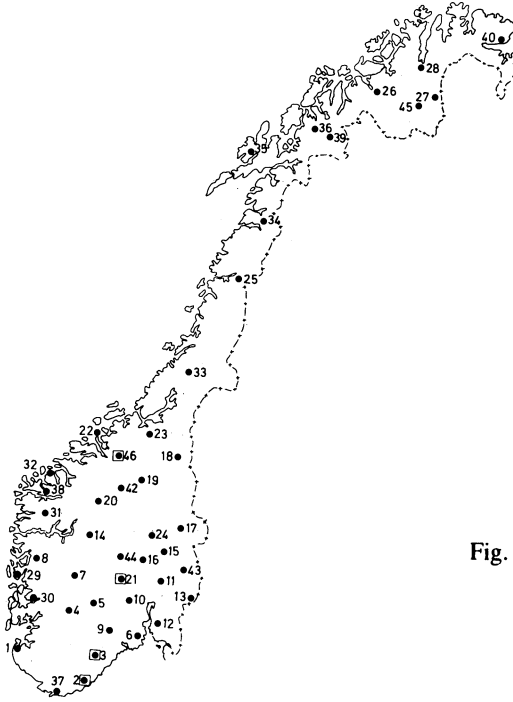


Fig. 1. Location of stations in the Norwegian groundwater observation network (LGN). Squares indicate groundwater stations near or in calibrated watersheds.

although decreased alkalinity and increased hardness have been observed in some cases.

This paper will present results from a preliminary evaluation of the status of groundwater acidification in Norway.

### Monitoring Program

The Norwegian groundwater observation network (LGN) organized through the Geological Survey of Norway (NGU) and the Norwegian Water Resources and Electricity Board (NVE), operates 46 groundwater stations for hydrogeological and chemical analysis (Fig. 1) all over Norway.

The National program for monitoring of long range transported polluted air and precipitation was started in 1980 following the completion of the research project "Acid precipitation - effects on forest and fish" (The SNSF-project) (Overrein et al. 1980). Monitoring of 5 calibrated watersheds is one of the projects within this program. In fall 1980 groundwater stations were established within or near 4 of these watersheds (Fig. 1).

The surface- and ground-waters from the calibrated watersheds have been com-

pared. In addition the water quality of 14 of the LGN groundwater stations were compared with those of lakes situated at a reasonable distance and within similar geological settings.

The groundwaters discussed in this report represent the fraction of groundwater present in glacial material and in the upper part of the groundwater zone.

### **Sampling and Analysis**

The four groundwater stations related to the calibrated watersheds were sampled monthly from Sept. 1980 and analyzed at the Norwegian Institute for Water Research (NIVA) for pH, conductivity, turbidity, Ca, Mg, Na, K, Al, Cl, SO<sub>4</sub>, NO<sub>3</sub>, SiO<sub>2</sub>, alkalinity and permanganate-value. The surface samples from the calibrated watersheds are collected weekly and analyzed for: pH, conductivity, Ca, Mg, Na, K, Al, Cl, SO<sub>4</sub>, NO<sub>3</sub> and alkalinity.

The stations of the groundwater observation network (LGN) are sampled twice a year (at high and low groundwater level). The analyses used in this paper were those from samples taken September-November 1980. The lakes whose chemistry were compared with the LGN-stations were selected from the lakes surveyed regionally in 1974-78 (Wright et al. 1977, Henriksen 1979a, 1979b).

### **Results and Discussion**

To compare the chemical composition of surface- and ground-waters the geological conditions at both sites must be comparable. Although the bedrock may be of same type the superficial deposits may vary in composition and origin and thus influence the water quality. Therefore, a comparison should be made of surface- and ground-waters known to be situated in similar geological settings.

Groundwater chemistry may be plotted in different ways, and most methods are based on expressing the chemical composition relative to geochemical equilibria (Hem 1970).

Our choice is shown in Fig. 2, illustrated with data from ephemeral springs and runoff in similar geologic settings in Sierra Nevada, U.S.A. (Feth et al. 1964). If the two types of water are identical in chemical composition, the plots of all components will fall on the 1:1 line. If the groundwater is concentrated relative to surface water, the points will fall on the line through origin and the ionic sums for the two types of water (Fig. 2); this line (the ionic sum line) will be positioned above the 1:1 line. Except for sodium the ground- and surface-waters illustrated in Fig. 2 have approximately similar relative compositions. The deviation for sodium may be due to a higher weathering rate of sodium than the other weathered

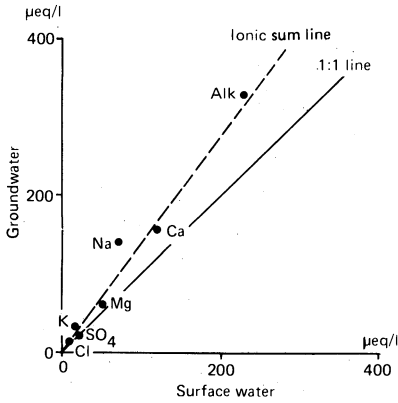


Fig. 2. Comparison of chemical composition of surface- and ground-water in Sierra Nevada, California, U.S.A., (Feth et al. 1964). The groundwater data represents mean values from 15 ephemeral springs. The surface water data represent mean values for an unspecified number of creeks in the same geologic area.

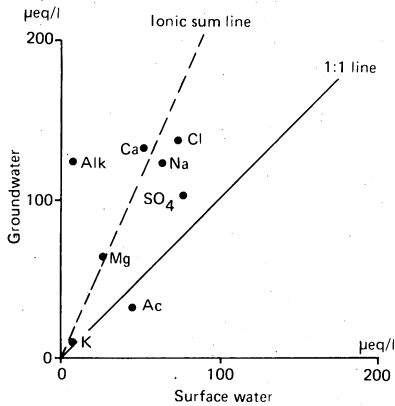


Fig. 3. Comparison of chemical composition of surface- and ground-water in Norway. The data represent mean values of 8 groundwater stations in the Norwegian groundwater observation network (LGN) and nearby lakes.

components in the groundwater zone.

This data presentation was made for the 14 LGN-stations and the selected comparable lakes (Table 1). An evaluation of the data shows that for 8 of those sets of data (LGN nos. 2, 3, 4, 9, 20, 24, 37 and 38) the weathering components Ca and Mg were situated close to the ionic sum line. This is used as a criterium for comparability of surface water and groundwater, and Fig. 3 shows plots of the mean values for the 8 sets of surface- and ground-water data.

The source for Na and Cl in surface water is normally the sea-salt spray content of precipitation. In addition to sea-salt spray the sulfate ions originate also from pollutants in precipitation (i.e. acid precipitation). Without geological sources for these components one would expect to find them on a line (not shown in Fig. 3) below the ionic sum line, and the position of this line relative to the 1:1 line would indicate the degree of concentration.

Calcium and magnesium plot very close to the ionic sum line (Fig. 3), whereas

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Table 1 Chemical composition of ground- and surface-water. Lake data are from Henriksen 1979a and 1979b.

Ground-water	pH	Cond. $\mu\text{S/cm}$	$\mu\text{eq/l}$										Lake	pH	Cond. $\mu\text{S/cm}$	$\mu\text{eq/l}$									
			Ca	Mg	Na	K	Cl	SO <sub>4</sub>	NO <sub>3</sub>	Alk	Ca	Mg				Na	K	Cl	SO <sub>4</sub>	NO <sub>3</sub>	Alk				
LGN 2	5.20	33.0	68	44	131	8	141	110	44	59	542	4.70	39.0	64	42	104	9	132	140	24	-20				
LGN 3	5.67	22.0	54	26	74	4	56	75	9	48	502	4.92	27.0	63	37	60	8	68	110	18	-12				
LGN 4	6.22	30.0	148	40	71	5	31	31	1	155	88.1	6.17	9.8	45	10	22	2	17	37	3	32				
LGN 9	5.32	32.2	108	50	60	6	76	135	19	53	86.1	4.84	23.4	65	24	30	6	40	100	11	-14				
LGN 10	6.43	36.6	131	69	91	26	28	154	5	166	90.1	5.97	23.8	151	48	48	8	31	104	4	120				
LGN 11	6.45	27.2	113	57	78	10	45	48	1	197	31.1	6.22	25.0	133	35	50	12	31	98	6	135				
LGN 15	5.44	25.6	101	25	50	16	34	96	1	111	47.1	6.11	10.2	57	17	26	6	9	42	5	42				
LGN 20	5.71	40.7	177	46	111	15	48	98	27	237	59.1	5.97	7.7	27	4	19	2	17	22	2	21				
LGN 24	5.99	30.1	200	35	48	6	23	85	11	198	47.1	6.11	10.2	57	17	26	6	9	42	5	42				
LGN 27	6.55	38.0	116	151	88	14	51	42	17	314	146.2	6.56	28.0	157	81	88	17	31	42	4	193				
LGN 31	5.62	34.1	51	36	131	7	166	35	21	107	530	6.01	14.0	39	16	48	7	56	35	7	14				
LGN 37	5.74	110	220	213	431	19	539	250	106	112	1.2	4.63	47	54	50	171	10	203	125	24	-25				
LGN 38	5.78	34.8	88	44	157	7	178	29	16	111	535	6.15	16.2	37	24	69	6	79	31	7	25				
LGN 43	5.91	16.9	42	42	41	10	40	60	3	52	40.1	5.67	23.7	92	58	46	7	40	87	4	49				

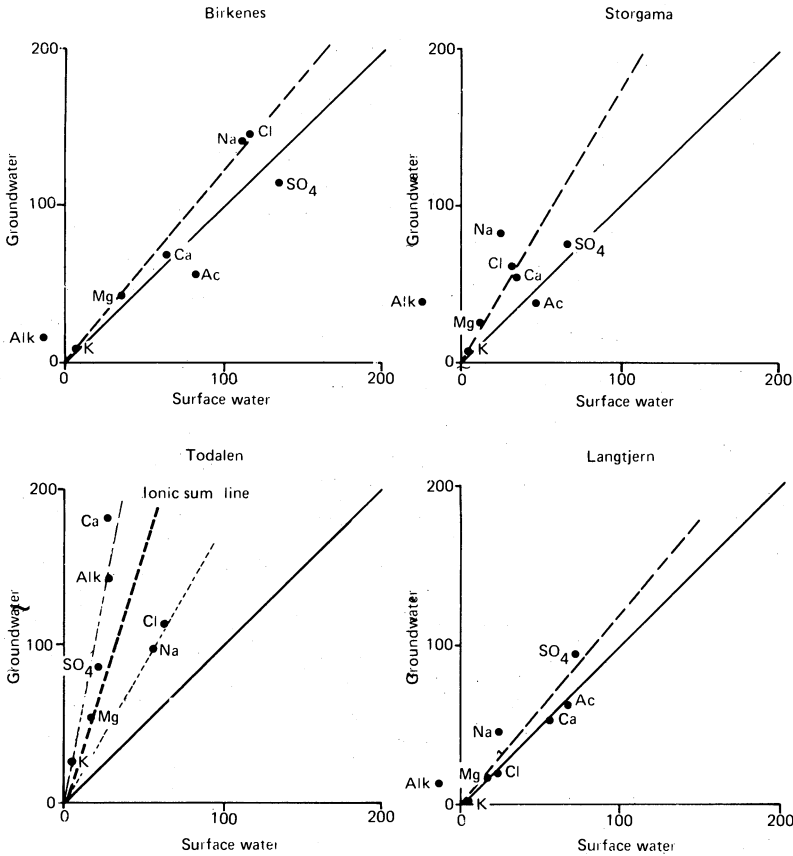


Fig. 4. Comparison of chemical composition of surface- and ground-water in 4 calibrated watersheds (Fig. 1). All units are in  $\mu\text{eq/l}$ .

sodium and chloride plot on a line below the ionic sum line. Sulfate plots significantly below both lines indicating that the sulfate concentration is relatively higher in the surface water than in the ground water. Alkalinity, on the other hand, is relatively higher in the groundwater than in the surface water. Since the first stage of acidification can be considered as an exchange of bicarbonate (alkalinity) with sulfate, Fig. 3 indicates that the groundwater is *less* acidified than the surface water in the same area and in similar geologic settings.

Acidification can be defined as the loss in alkalinity (Henriksen 1979c) and is operationally defined as the difference between “preacidification” alkalinity (original alkalinity,  $Alk_o$ ) and present-day alkalinity ( $Alk_t$ )

$$\text{Acidification (Ac)} = Alk_o - Alk_t \quad (1)$$

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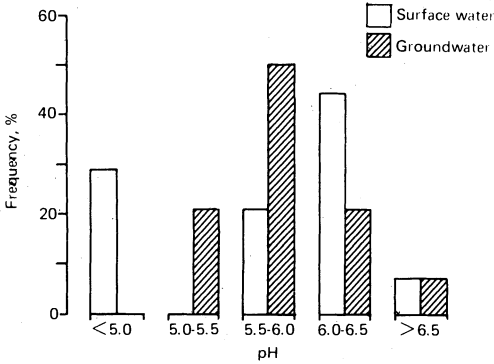
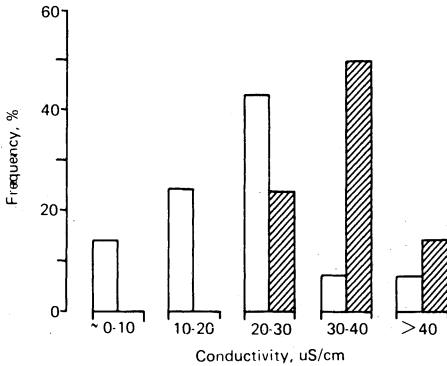


Fig. 5. Frequency distribution diagrams for pH and conductivity for the 14 ground- and surface-waters referred to in Table 1.



The original alkalinity of sample can be estimated from the sum of its non-marine calcium and magnesium concentrations (Henriksen 1980). This implies that present-day data can be used to estimate acidification according to Eq. (1). The estimated acidification values ( $A_c$ ) for the mean values of the 8 sets of ground- and surface-waters are also plotted in Fig. 3 (30 and 46  $\mu\text{eq/l}$  for ground- and surface-waters, respectively). The position of the point indicates again that the surface waters are more acidified than groundwaters. If they were equally acidified, the point would fall on the 1:1 line).

Diagrams corresponding to Fig. 3 for the four calibrated watersheds Birkenes, Storgama, Langtjern and Todalen (Fig. 1) are shown in Fig. 4. The first three are situated in acidified areas of southern Norway, while Todalen is situated in an area not significantly affected by acid precipitation (weighted-average precipitation pH 4.88 in 1980). In Birkenes, Storgama and Langtjern the alkalinites are higher in the groundwater than in the surface water, and the acidification ( $A_c$ -values) are higher in the surface waters than in the groundwaters.

In the diagram representing Todalen the ionic sums are divided into two groups of components, one for the sum of sodium and chloride and one for the remaining

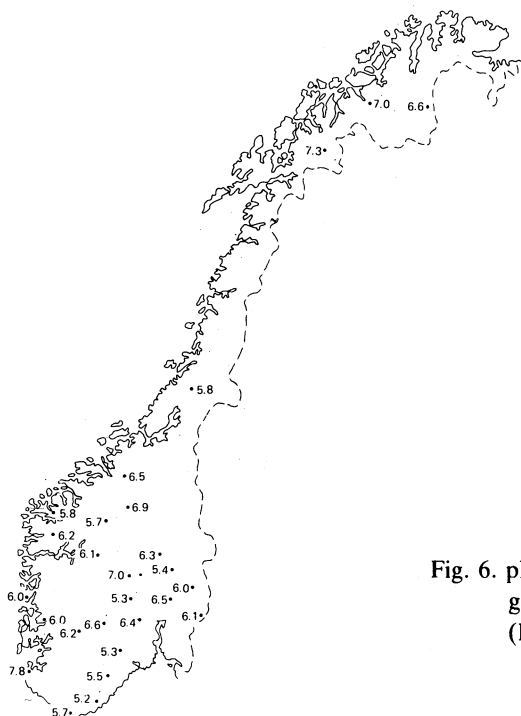


Fig. 6. pH in samples from the Norwegian groundwater observation network (LGN) sampled during fall 1980.

ions. There is a clear relation between the groundwater and surface water. Except for sodium and chloride are all the components in the groundwater concentrated in nearly the same ratio to the surface water. This concentration effect is most likely due to an increased weathering in the groundwater because of longer contact time between water and bedrock. Sodium and chloride are probably concentrated as a consequence of evaporation. The positions of points for alkalinity and sulfate indicate that neither the groundwater nor the surface water is acidified. Estimates of acidification according to Eq. (1) give a similar indication.

Frequency distribution diagrams for the 14 ground- and surface-waters (Table 1, Fig. 5) show that the salt content (conductivity) is higher in groundwater than in surface water, as is also shown by the position of the ionic sum line in Fig. 3. The average conductivity of the groundwater is 67% higher than the conductivity of the surface water. None of the groundwater sites have a pH less than 5.0, while nearly 30% of the lakes have a pH less than 5.0. On the other hand, 20% of the groundwater localities are found in a pH range (5.0-5.5) where no lakes are found. In this particular pH range the bicarbonate buffer is practically exhausted. In the acidified areas of Europe and North America one often finds a lower frequency of pH observations in this range than in the ranges above and below (bimodal pH-distribution) (Wright and Gjessing 1976).



## *Acidification of Groundwater in Norway*

In addition to the 14 groundwater stations already discussed additional 13 stations were sampled during fall 1980. The pH values (Fig. 6) show a distribution not unlike the one found from the regional lake survey carried out in southern Norway during fall 1974 (Wright and Henriksen 1978) with lowest pH's in southernmost Norway.

### **Conclusions**

This simple and rather incomplete investigation indicates that acidification has occurred in groundwater present in superficial deposits and in the upper part of the groundwater zone in areas of Norway where the surface water is acidified. The data are too few to draw definite conclusions; more extensive investigations at several levels of the groundwater in Norway are requested. These levels could be wells and springs in superficial deposits and drilled wells in bedrock, both on local and regional basis.

### **References**

- Drabløs, D., and Tollan, A. (eds.) (1980) Ecological impacts of acid precipitation, SNSF-project, 383 pp.
- Feth, J. M., Roberson, C. E., and Polzer, W. L. (1964) Sources of mineral constituents in water from granitic rocks. Sierra Nevada, California and Nevada. U.S. Geological Survey, Water-Supply paper 1535-I, 70 pp.
- Hem, J. (1970) Study and Interpretation of the Chemical Characteristics of Natural Water. U.S. Geological Survey, Water-Supply paper 1473, 363 pp.
- Henriksen, A., (1979a) Regional surveys of lakes and snowpack winters 1976-77 and 1977-78. SNSF-project, TN 46/79, 21 pp. (In Norwegian with English summary).
- Henriksen, A. (1979b) Regional chemical survey of large lakes in Southern Norway winter 1979. SNSF-project, TN 50/79, 24 pp. (In Norwegian with English summary.)
- Henriksen, A. (1979c) A simple approach for identifying and measuring acidification of freshwater. *Nature*, 278, pp. 542-545.
- Henriksen, A. (1980) Acidification of freshwaters – a large scale titration. In: Drabløs, D. and Tollan, A. (eds.) Ecological impacts of acid precipitation. SNSF-project, 68-74.
- Hultberg, H. and Johansson, S. (1981) Acid groundwater. *Nordic Hydrol.*, 12, pp. 51-64.
- Overrein, L. N., Seip, H. M., and Tollan, A. (1980) Acid precipitation – effects on forest and fish. Final report of the SNSF-project 1972-80. 175 pp.
- Wright, R. F., Dale, T., Henriksen, A., Hendrey, G. R., Gjessing, E. T., Johannessen, M., Lysholm, C., and Støren, E. (1977) Regional surveys of small Norwegian lakes October 1974, March 1975, March 1976 and March 1977. SNSF-project IR 33/77, 153 pp.
- Wright, R. F., and Gjessing, E. T. (1976) Acid precipitation: Changes in chemical composition of lakes. *Ambio* 5, pp. 219-23.

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Wright, R. F., and Henriksen, A. (1978) Chemistry of small Norwegian lakes, with special reference to acid precipitation. *Limnol. and Oceanogr.* 23, pp. 487-98.

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