T. Schneider (Editor)/*Acidification and its Policy Implications*

ACIDIFICATION AND DRINKING WATER - GROUNDWATER

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ABSTRACT

The atmospheric load of acids exceeds the base production by weathering of non-carbonate rocks and soils in many parts of Europe. This has resulted in changes in the quality of drinking water from groundwater wells.

A national well survey in Sweden together with an investigation of the penalty for corrosion of indoor water installations has revealed substantial costs of 150 M SEK per year for water damages caused by corrosion due to acidification. An estimate based on a municipal well survey of 10,000 private wells has revealed a government expense of 500-1,000 M SEK for alkalizing private well water.

As a result the Swedish government has allocated funds for a trial period for subsidies for countermeasures to private wellowners with acid, corrosive drinking water.

INTRODUCTION

The quality of drinking water from groundwater supplies has changed in many countries in Europe since the 1950s. Changes influenced by acidification may be caused by atmospheric deposition, by nitrogen fertilizing in farming and/or changes in land use. This paper presents the effects and economical consequences of drinking water influenced by atmospheric deposition and countermeasures taken in Sweden. A presentation of atmospheric acid loading and base production from weathering of silicate minerals and effects of acidfication in the Nordic countries will be made. The changes of well water quality in the last decades will be discussed.

GENERATION AND DEPLETION OF ALKALINITY - THE ACIDIFICATION BUDGET

Long-term changes of the groundwater quality will occur if the total acid load exceeds the base production from weathering of soils and rocks.

The atmospheric load of acids from sulfate and nitrogen compounds ranges from 0.1 keq/ha,yr in northernmost Sweden to 1.5 keq/ha,yr in southern Scandinavia and 3-7 keq/ha,yr in the most exposed areas of Central Europe.(ref.2) The extension of slowly weathering rocks in Europe is presented in fig 1 and pH in precipitation over Europe in fig 2.

Base production of bicarbonate from weathering of acidic and intermediate acidic rocks, i.e. granites, gneisses, sandstones and quartzites is in the range of 0.1-2.0 keq/ha,yr, which in many cases is less than base consumption by total acid deposition. This will result in acidification of groundwater over time.

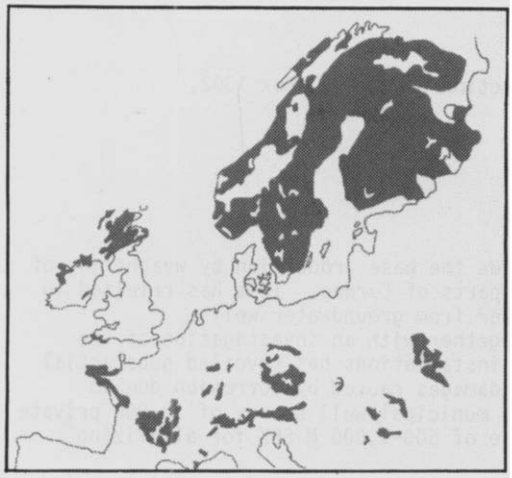

Fig. 1. Acidic and intermediate acidic hard rocks, i.e. granites, gneisses, sandstones, quartzites in part of Europe.

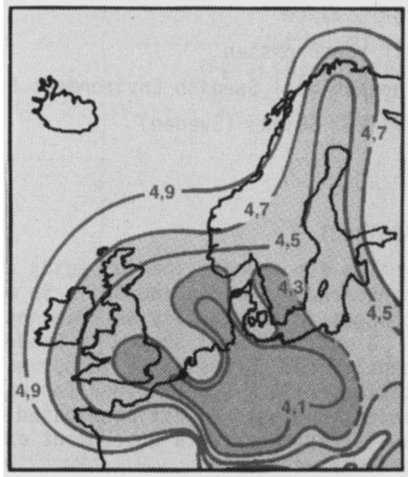

Fig. 2. pH in precipitation over part of Europe. (ref.12)

Weathering of carbonate rocks and soils produces alkalinity in the order of 4-16 keq/ha,yr. This is often more than consumption by acid load. The effects on groundwater is increased alkalinity, hardness and sulfate content and eventually increased content of nitrate. Atmospheric loads of acids and base production potential in different parts of Europe are presented in Table 1.

TABLE 1
Average yearly atmospheric load of acids and the base production potential from silicate and limestone weathering in different parts of Europe. (ref.2)

	Sulfur Wet + Dry g/m^2	Sulfur + Nitrogen keq/ha	HCO_3-Prod from Weathering Silicate keq/ha Extreme	Normal	Limestone keq/ha
N Scandinavia	0.2	0.1	0.1-0.4	0.4-2	4-16
C Scandinavia and Scotland	1.0	0.6	0.1-0.4	0.4-2	4-16
S Scandinavia	2.0	1.3	0.2-0.4	0.4-2	4-16
Central Europe	5-10	3.7	0.2-0.4	0.4-2	4-16

Alkalinity production at shallow soil depths $\leq$ 4 m,may be in the range of 0.1-0.4 keq/ha,yr for sand and glacial till if the minerals lack calcium carbonate. For greater depths the base production may be 0.4-2 keq/ha,yr.

In Sweden the median depth of private dug wells is 4.1 m and for drilled wells in hard rocks 68 m. Dug wells are performed in glacial till or in sandy soils. Critical load for acid deposition for shallow groundwater may be in the range of 0.2-0.4 keq/ha,yr for glacial till and 0.1-0.2 for sand. The acidification budget for different parts of Sweden can be studied in fig 3.

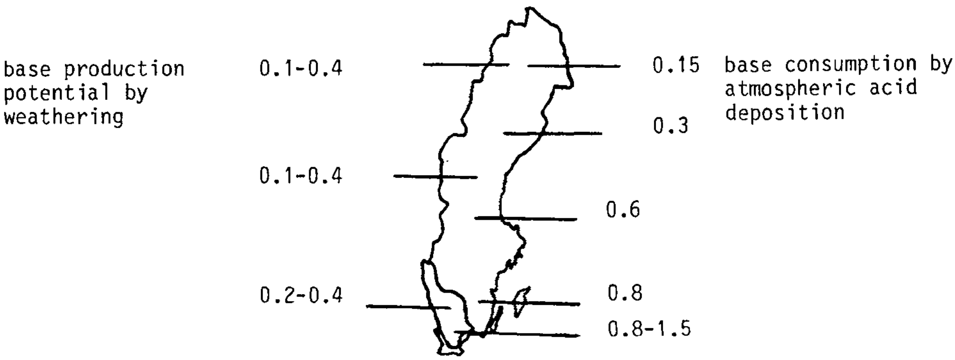

Fig. 3. Base production potential in non-calcareous 0-4 m deep soils and base consumption by wet and dry atmospheric acid deposition, keq/ha,yr.

GEOLOGY AND THE WATER SUPPLY STRUCTURE IN THE NORDIC COUNTRIES CONTRIBUTE TO THE EXTENT OF ACIDIFICATION OF OUR WATER SUPPLIES

Acidification of groundwater by acid rain is mainly a phenomenon in areas with slowly weathering hard rocks and soils, and where drinking water is drawn from shallow wells. Areas with acidic or intermediate acidic hard rocks are shown in figure 1. Apart from Northern Europe, such geological conditions are found in several areas in Central Europe, where acid deposition is also high. Figure 2 shows pH in precipitation over Northern Europe.

As the weathering rate is considered to be independent of pH in the range pH = 4.0-7.0, weathering becomes a function of the transit time for water in the soil or rock. This means that water from shallow wells and water with short transit time in the basin-aquifer will first become affected by acidification. As time goes on, the water in deeper and deeper wells will be effected.

In the Nordic countries, with sparse population areas, a great part of the water supply consists of private shallow dug wells or drilled wells in hard rocks. An overview of the water supply conditions is given in table 2, where information on public water supply, permanent residents private water supply and water supply for recreation houses is tabulated.

TABLE 2

Overview of water supply structure in the Nordic countries (22.5 M people).

Public water	Sweden	Norway	Denmark	Finland	Iceland
Groundwater and artificial groundwater (%)	49	5	100	46	-
Surface water (%)	51	95	0	53	-
Private groundwater wells thousands of homes					
Permanent residents	400	350	200	500	-
Recreation	650	250	30-80	250	-
Number of people x 10^6 population	8.3	4.1	5.1	4.8	0.23
Permanent residents	1.1	0.8	0.5	1.3	-
Recreation	2.0	1.0	0	1.0	-

17 % of the total Nordic population have their own private wells. If recreation houses are included, there are 2.6 x 10^6 private wells all together.

EFFECTS ON DRINKING WATER DURING DIFFERENT STAGES OF THE ACIDIFICATION PROCESS

Water with pH < 7

1. When the total acid load exceeds the base production in the ground, the base saturation will steadily decrease. In this phase no long-term changes in pH will occur but changes will be seen in alkalinity, hardness and eventually in sulphate and nitrate concentration.

   If pH $\leq$ 6.5 and HCO_3 < 60 mg/l and if the sulfate content becomes higher than the alkalinity, this will result in higher pitting corrosion in primarily copper pipes.

2. When pH reaches pH < 6 the copper content will reach 2-15 mg/l Cu in tap water with copper pipes after some 10 hours of contact time.

3. When pH $\leq$ 5.0-5.5 the aluminium content will rise to 0.2-2 mg/l Al. No systematic surveys on heavy metals in acid groundwater are carried out so far in Sweden.

Water with pH > 7

Water from carboniferous aquifers shows increasing alkalinity, hardness, sulfate and in some cases nitrate contents.

DOCUMENTED INFLUENCES ON GROUNDWATER IN SWEDEN BY ATMOSPHERIC ACID DEPOSITION

Changes of alkalinity and sulfate contents in well water with pH below 7 has been documented from well surveys, two of which are presented in figures 4 and 5. The implications experienced have been increased pit corrosion on water installations.

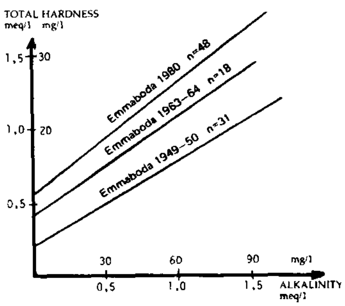

Fig.4. Regression lines for hardness alkalinity in dug wells, S Sweden. (ref.6)

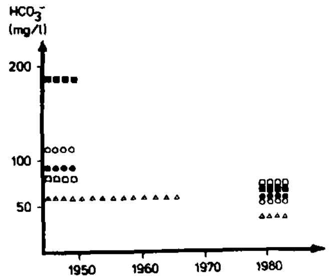

Fig. 5. Changes in alkalinity in 2000 dug wells in S Sweden. (ref.7)

Time series from the Swedish groundwater monitoring network, established in 1968, have not given as pronounced indications of influence of acidification as have these two well surveys. This may be explained by the fact, that two different groundwater regimes are being studied.

Well surveys represent integrated water with different transit times, times which have often been reduced by pumping. Piezometers represent water within a certain region and with a specific transit time.

The impact of acidification on groundwater with pH > 7 in carbonate rocks, as documented from south Sweden in time series since the 1950s, has been: increasing contents of alkalinity, hardness, sulfate and nitrate. No studies concerning effects on for example corrosion, has so far been undertaken for these waters where pH > 7.

Corrosion on concrete casing in wells has resulted in leakage of surface water into the wells with contamination of organic and microbiological compounds of the drinking water.

Similar changes in well water quality caused by acid rain has been documented in surveys of private, shallow dug wells and municipal groundwater supplies. The alkalinity versus hardness diagram does not involve effects of fertilisation or changes in land use. The material on 2.000 dug wells from Western Sweden indicates decreasing alkalinity. Numerous wells on the Swedish West coast, both dug wells and wells drilled in hard rocks, have lost alkalinity and have pH's below 5.0. Drilled wells in hard rocks with shallow or no overburden, are more influenced by acidification, than wells with a thicker cover of for example glacial till soils.

A statistical analysis of data from 1960, 1962, 1968 and 1980 from VAV - The Swedish Water and Waste Water Works Association - from approximately 150 public surface and groundwater supplies showed strong evidence of acidification. Significant changes of the alkalinity to hardness ratio had occurred between 1960 and 1980 for both types of water supplies. No statistical change in pH was revealed for the material as a whole. No classification of geology according to base production was performed. (ref.4)

The main consequences of acidification are that well waters have become more corrosive to metal water pipes, have increased copper contents in tap water and increased aluminium contents in groundwater. More comprehensive studies on the presence of heavy metals in groundwater are lacking in Sweden.

COSTS OF CORROSION OF PRIVATE WATER SUPPLY INSTALLATIONS IN SWEDEN

In order to estimate the magnitude of corrosion on water supply installations, the total cost for indoor water damage that was repaid by the insurance companies was investigated. The money refunded in 1982 amounted 1,100 M SEK. Out of this amount 340 M SEK was due to corrosion and out of this about 140 M SEK was estimated to have been caused by acidification. These costs will increase with continuing high depositions of acid. The mean cost payed for by the insurance companies amounted 10,000 SEK per client. It is not known whether the cost of corrosion is mainly associated with private water supplies. It should be noted that public water supplies mainly have alkalizing treatment of the drinking water. If this is the case 140 M SEK should be assigned to 1.1 M people or about 0.4 M private homes. The cost-benefit ratio for filter-installations will then be 1.0:1.7-1.0 not including costs associated with water damage on sanatory goods, laundry and increased content of metals, mainly copper in tap water. (ref.9)

A NATIONAL SURVEY AND GOVERNMENT FUNDS TO COUNTERACT ACIDIFIED PRIVATE WELLS

The National Swedish Environment Protection Board has requested the municipalities to perform voluntary surveying of 100-200 wells with the purpose of characterizing and quantifying the problem of acid, corrosive well water. 70 municipalities have undertaken such surveys. In December 1985 the Swedish government allocated funds to assist private wellowners with very corrosive well water and/or with copper contents in tap water over night exceeding 3 mg/l Cu.

The criteria used to qualify for government funds for water treatment installations are apart from the copper content being > 3 mg/l Cu, that pH < 6.5, HCO_3 < 60 mg/l and the sulfate content being higher than the alkalinity. All these three conditions must be fulfilled together.

70 municipalities out of 284 have carried out the survey in 1985 and another 40-50 surveys will be carried out in 1986. Results from about 10,000 well analyses and estimates based on information of the occurrence of acid surface water indicate that 70,000 private resident homes and 20-50,000 vacation houses have very corrosive well water. The majority of these wells being influenced by acidification.

Alkalizing filters for private homes can be purchased for 4,000-15,000 SEK. The total investment for installation of alkalizing filters and/or soil liming have been estimated to 500-700 M SEK for wells for household consumption of permanent residents only.

ACIDIFICATION AND DRINKING WATER IN SOME EUROPEAN COUNTRIES

Norway

Acid precipitation in Southern Norway has a pH = 4.3-4.5, which has caused considerable acidification of surface waters. Water drawn from surface water accounts for 95 % of all public water supplies. From the groundwater observation network there are 46 monitoring stations reporting water quality.

The following information is from shallow groundwater in soil aquifers in Southern Norway (ref.5):

pH = 5.2-5.7

HCO_3 = 1-5 mg/l

SO_4 = 1-12 mg/l

Cu = 0.8-4.4 mg/l

This water quality will be very corrosive to water installations, giving pitting corrosion and high copper content in copper pipes. The amount of wells with corrosive water is not known.

Finland

Total wet and dry deposition is less in Finland than in Sweden and Norway. Wet deposition of sulfate only locally exceeds 0.10-0.15 keq/ha,yr SO_4. Snow, which is here the most important part for recharge of groundwater, has had a pH = 4.4-5.0 during the last 10 years. The impact of acidification on groundwater is not yet fully known.

A groundwater observation network was established by the National Board of Waters in 1975-76. Time series of 8 years of water quality data are available. Regression analyses show a significant increase in sulfate, calcium and aluminium. No significant changes in pH have been observed. Some medium values are given below. (ref.14)

pH = 6.3

HCO_3 12 mg/l

SO_4 = 6.1 mg/l

Ca = 4.5 mg/l

el-conductivity = 6.0 m S/m

This indicates that well water corrosive to water installations may occur. The occurrence and the number of such wells are not known.

Denmark

A survey carried out in the municipality of Ringkjoebing in West Jylland showed the following pH-distribution in 2,000 private wells (ref.1):

pH	< 5	5-6	6-7	> 7
Wells %	11	35	30	24

Water having pH $\leq$ 5 had increased contents of aluminium of 0.2-9.1 mg/l Al.

In public groundwater supplies in 10-25 m deep borings pH and alkalinity had decreased between 1950-54 and 1980-86 from pH = 6.5 to pH = 5.6 and from 1.7 to 0.7 mg/l HCO_3.

An analysis carried out of the hydrogen budget using the Schroeder model indicated, that 4 % of the total acid deposition could be allocated to acid rain and the remaining part to agriculture. Only 30 % of required lime dosage of 1,300 kg/ha,yr was being applied.

In Holland similarly 9-17 % of the acid load is considered being due to atmospheric deposition, farming being responsible for the remaining part causing severely acidified Dutch groundwater. (ref.10)

Federal Republic of Germany

Investigations carried out in the forested Taunus quartzite hills show an acidification of shallow groundwater in this non-agricultural area. Total deposition of acids is here 4 keq/ha,yr. The sulfate content in groundwater has risen from 5 mg/l SO_4 in the 1960-ies to 20 mg/l SO_4 25 years later. pH is low but above pH = 5.6. A comparison between shallow and deep groundwater from horizontal rock tunnels for water supply (stollen) show a great difference between shallow and deep groundwater. Nitrate range from 10-30 mg/l in shallow and from 3-15 mg/l NO_3 in deep groundwater. The sulfate range is 20-50 mg/l SO_4 in the shallow groundwater and 2.5-25.0 mg/l SO_4 in the deep groundwater. (ref.8).

This indicates that groundwater supplies in forested areas with acidic or intermediate acidic rocks with low buffer capacity have become acidified from acid precipitation. This will also be the case in many other areas in Central Europe with acidic rocks.

CONCLUSIONS

The total atmospheric load of acids exceeds the base production in soils and rocks in many parts of Europe. This is especially the case where slowly weathering rock materials are prevailing, i.e.granites, gneisses, quartzites, sandstones. In these geological environments the base saturation will steadily decrease and eventually approach zero. This will imply that the groundwater will become influenced by acidification, primarily shallow groundwater and with time, deeper groundwater. At first private water supplies from shallow wells and later public groundwater supplies. For water with pH < 6.5 and low alkalinity pitting corrosion will increase in indoor water installations, spec. primarily copper installations as a consequence of decreasing alkalinity and increasing content of sulphur. This will occur without any decrease in pH. The second stage is when pH starts to decrease. For waters with pH around and less than pH = 6, the copper content will increase drastically in tap water from copper pipes. After contact time of 2-3 hours the copper content may increase to 3-5 mg/l. This may cause diarrhoea to infant children. For low pH, less than 5.0-5.5, the metal contents in the groundwater itself will increase. Primarily aluminium with concentrations 0.1-1.0 mg/l being frequent. The knowledge and documentation of background values and the influence of acidification on metals in groundwater is presently poor.

17 % of the 22 million in the Nordic countries have private water supplies. Decreasing alkalinity and increasing sulphate contents have resulted in corrosion as a consequence of atmospheric acid deposition.

A national survey has revealed an investment cost of 500-1,000 M SEK for countermeasures for 100,000 Swedish private wells with acid corrosive drinking water. No estimates on public health consequences have so far been made. Critical load limits for acid deposition in order to avoid negative consequences for drinking water from groundwater supplies have to be studied for different geological settings as an input to political decisions on reduction of acid emissions.

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