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An Attempt to Reduce Nitrate Content in Ground Water Used for Municipal Water Supply by Changing Agricultural Practices

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The heavy use of manure and fertilizers has in some parts of Sweden resulted in unacceptable concentrations of nitrate in ground water used for private and municipal water supply. In Halland for example, several of the municipal water supplies have nitrate concentrations close to 50 mg/l. Either anionic exchange or mixing with water with less nitrate are used to reduce the nitrate content in the distributed water. However, some wells have been abandoned because of high nitrate concentrations. In this study an attempt is made to reduce the nitrogen contamination of the ground water at the source. In well recharge areas the agricultural practices are investigated and, if necessary, alterations are proposed to the farmer in order to decrease the nitrogen leaching from the soil profile. The effect of these improvements is continuously studied in soil and ground water. An action plan is proposed for water supplies with dominating arable land in the recharge area.

Background

The use of inorganic fertilizers has increased markedly after the second world war. At the same time livestock feeding has been concentrated into fewer but bigger units. Especially in areas with high livestock density the total nitrogen applications very often exceed crop requirements (Andersson 1973, 1982; Joelsson and Pettersson 1982), and may therefore cause pollution of ground waters.

High nitrate content in ground water used for private and municipal water supply has become a common problem in southern Sweden, especially in districts

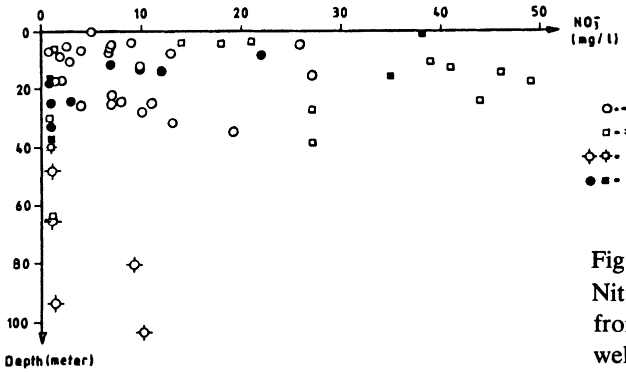


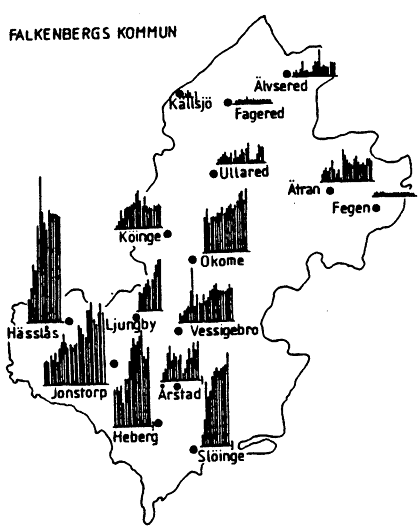
Fig. 1.
Nitrate concentration in water from different kinds of municipal wells in Halland.

with intensive agriculture on sandy soils. It has been estimated that about 100,000 people here are consuming water from private wells with a nitrate concentration above 50 mg/l (Thoms and Joelsson 1982). Water with more than 50 mg/l of nitrate is in Sweden as in many other countries, not recommended for small children.

Halland is a county where nitrate pollution of ground water is a serious problem. A classification of all the municipal wells in Halland by the percentage of arable land in the recharge area shows that nitrate concentrations above 30 mg/l only occur where the percentage of arable land exceeds 75 per cent. The nitrate content is usually lower in deeper wells (>25m) or when there is a protecting clay layer close to the well (Fig. 1).

The nitrate content in municipal water supplies has also increased over time (Andersson 1978) see Fig. 2.

These results, which agree with other similar investigations, indicate the importance of land use for ground water quality.



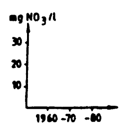


Fig. 2.
Nitrate content in municipal water supplies in a part of Halland having mostly sandy soils. Forestry dominate in the upper half and agriculture in the lower half of the area.

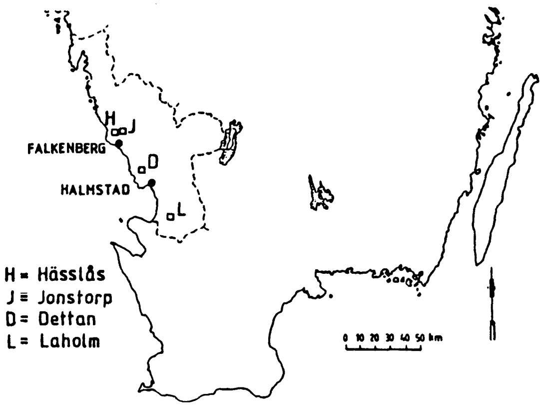


Fig. 3. The county of Halland.

In municipal water supply the nitrate problem has been dealt with by taking measures outside the pollution source. Such measures are mixing waters of different nitrate quality, installation of ion exchange equipment, drilling new and deeper wells. These options are fairly expensive but are, on a short term basis, the most appropriate to water suppliers. Long-term measures must, however, involve preservation of water resources. In areas with intensive agriculture the leaching of nitrate from arable land in most cases is the main pollution source and preservative measures must consequently be focused on the agricultural practices in the recharge area of the well.

Preventive Measures to Reduce Nitrate Leaching from Arable Land

An attempt to solve the nitrate pollution problem by taking measures at the source has been made in Laholm. In one of the municipal water supplies the nitrate concentrations were observed to increase during the early seventies.

The recharge area of the well consists of a 6 m deep sand layer underlain by clay. Up to 1975 the land was used for crop production, mainly cereals and potatoes, and the use of nitrogen fertilizer was high. On some areas as much as 800 kg N/ha/year has been applied.

The water authorities assumed that nitrate leaching was the main pollution source and in 1975 they introduced restrictions on fertilizer use as an attempt to reduce the nitrate pollution. The upper limit for fertilizer application was set to 100 kg N/ha/year. On considerable parts even less was actually used in the following years. About 6 ha close to the well were also shifted to pasture growing.

In less than two years the nitrate concentration fell from about 80 to 40 mg/l and has been below 30 mg/l since 1979 (Fig. 4).

Another example is near Falkenberg, where a 4 m deep private well in sandy sediments is surrounded by arable land (Fig. 5).

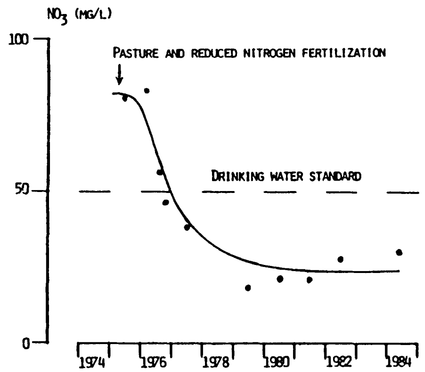


Fig. 4. Change of nitrate concentration in a municipal water supply in Laholm where nitrogen fertilization was reduced in the recharge area.

Here the nitrate concentration fell from about 80 to 20 mg/l as a consequence of changing the land use from cereals to grass production and by reducing nitrogen fertilization in the early seventies. In the spring of 1982 the ley was ploughed up and barley was sown. The nitrogen fertilization was increased to about 100 kg N/ha, an application which is recommended for this type of crop in this region. During the two following years the nitrate concentration of the water has once again increased to about 80 mg/l.

Even if the documentation of these two examples is not quite satisfactory and rather drastic measures have been taken, the results clearly illustrate the agricultural impact on the ground water. The examples also show the possiblility of decreasing nitrogen content by changing agricultural practices.

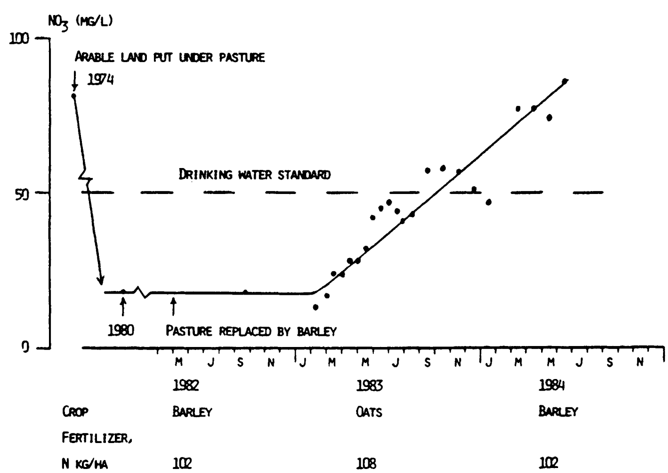


Fig. 5. Fluctuation in nitrate concentration in a well used for private water consumption as a function of changed land use. Time delay between action and response is appr. 9 months.

Detailed Studies of Three Municipal Water Supplies – A Research Project

In this study, which started in autumn 1982, an attempt is made to reduce nitrate content in three nitrate polluted municipal water supplies (Hässlås, Jonstorp and Dettan) in Halland by changing agricultural practices. The nitrate contamination caused by farming activities is also being related to hydrological and hydrochemical conditions. Nitrate concentrations for Hässlås and Jonstorp from 1960 to 1980 are shown in Fig. 2.

Five private nitrate polluted shallow wells are also being studied. But these are not further discussed here.

The Recharge Areas

The three water supplies have similar geological surroundings. They are placed in connection to the ice-marginal glaciofluvial deposits, typical of Halland. These deposits are known to be complex. The dominating coarse glaciofluvial sediments are often mixed with till and finer sediments. The thickness of the deposits are approximately 10-20 m.

In Jonstorp sand predominates in the surface layers and the drainage is good. The topography is rather uneven and the depth to the ground water table is typically about 2.5 m.

In Hässlås and Dettan the sandy soils are mixed with smaller areas with silty/clayey or gravelly surface layers. In Hässlås the topography is rather flat and the ground-water table is shallow (1-2.5 m). In Dettan where the landscape is more hilly the depth to the water table is about 6 m in the most distant part while artesian conditions prevail close to the well. In Hässlås and Dettan small areas are pipe drained.

All wells are 15-18 m deep and it is possible to extract about 15 l/s at Jonstorp and Dettan and about half of that amount at Hässlås. However, the wells are not used to their full capacity. The nitrate content in the water at Hässlås and Dettan is about 50 mg/l and at Jonstorp 70-120 mg/l. At Hässlås and Dettan ion exchange and water mixing are practiced to reduce the nitrate content. The more polluted water at Jonstorp has not been distributed since 1979 because of its high nitrate level.

Agricultural land dominates (70-80%) the three recharge areas. The main crops are cereals (60%) and temporary pasture (20%) but other crops such as potatoes, corn and leguminous plants also exist. Especially at Jonstorp the share of barley is high, while temporary pasture constitutes a great part at Hässlås. The livestock density and the production of animal waste is high. The livestock density at Jonstorp is 1.4 cattle units/ha and at Hässlås and Dettan 1.0 cattle units/ha (1 cattle unit = 1 dairy cow or 10 fattening pigs etc).

Methods

The recharge areas are estimated from ground-water level observations in tubes and private wells and from the topography.

The agricultural practices on the farms in the recharge areas are documented through farm visits.

The nitrogen content of ground water and the effect of measures are studied in soil profiles (2-4 m deep), in private wells and in tubes (0.5-15 m deep) distributed within the recharge areas.

Results

The recharge areas for Hässlås, Jonstorp and Dettan are about 50, 100 and 150 ha, respectively. Considering the rather complex geology it is clear that the ground-water flow pattern is also complicated. In Jonstorp and Dettan test drillings and ground-water level observations have revealed the existence of fine textured layers and separate aquifers in parts of the defined recharge areas.

The total application of nitrogen at Jonstorp was found to considerably exceed recommendations mainly due to an intensive use of manure. Also at Dettan the total fertilizer use was close to the upper limit of recommendations. At Hässlås the fertilization was more moderate except for small areas that, however, might be important infiltration areas due to coarse soils.

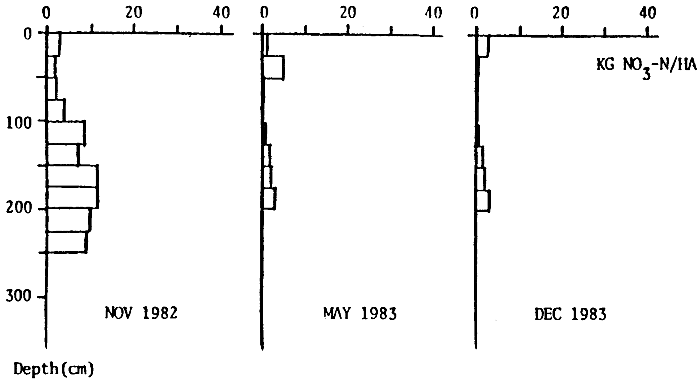
The soil cores reveal a great variation in nitrate nitrogen in soil profiles as a function of fertilization and crop type. Pasture growth leaves little nitrogen available for leaching while an application of manure can be followed through the movement of nitrate nitrogen downward the soil profile (Fig. 6).

It has also been found that the nitrate leaching from fields with sugar-beets and autumn cereals is low compared to fields with spring cereals and potatoes (Table 1.).

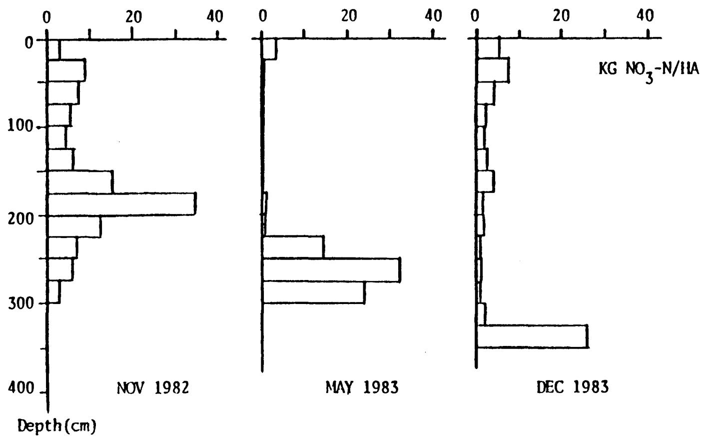
The lower half of Fig. 6 also shows that the nitrate has moved approximately 1.5 m per year in the unsaturated zone apparently without reduction. Provided nitrate

Table 1 – Nitrate nitrogen in soil profiles (0-1 m). Mean values in November 1982 and 1983 after different type of crops.

	NO_3-N kg/ha	
Pasture	3	n = 2
Spring cereals undersown with grass	9	n = 4
Sugar-beet	18	n = 3
Autumn cereals	32	n = 5
Spring cereals	50	n = 13
Potatoes	53	n = 9



	Crop	Fertilizer applic. Kg N/ha	Time of applic.
1982	Oats undersown by grass	90 Inorg	Spring 1982
1983	Temporary pasture	70 Inorg	Spring 1983
		50 Inorg	Summer 1983



	Crop	Fertilizer applic. Kg N/ha	Time of applic.
1982	Barley	225 Liquid Manure	Autumn 1981
		100 Inorg	Spring 1982
1983	Rye	70 Inorg	Autumn 1982
		80 Inorg	Spring 1983

Fig. 6. Nitrogen profiles under pasture (upper half) and under heavy manure application (lower half). The nitrogen pulse in the lower half contains about 70 kg N/ha, which gives about 300 mg NO_3/l in the soil solution.

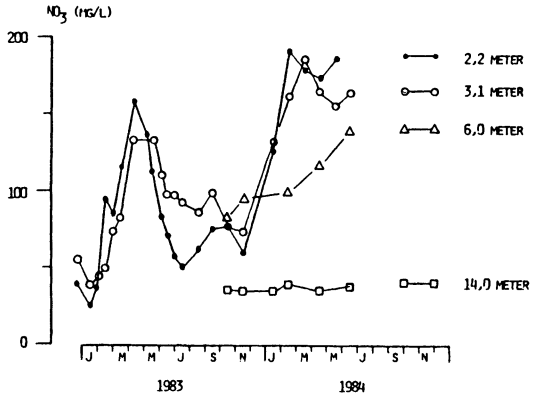


Fig. 7.
Nitrate in ground-water tubes placed at different depths, Dettan.

is a "perfect" tracer and using water content data the percolation can be estimated to 375 mm per year. Other soil profiles indicate percolation rates of the same order. This gives a residence time of the water in the unsaturated zone of about 1-2 years in most parts of the recharge areas. Considering the thickness of the sediments and the porosity (35-40%) it is obvious that the turnover time of the ground-water reservoir is very much longer.

The shallow ground-water tubes and the private wells are tested for nitrate content once a month. High nitrate concentrations are generally found in tubes and wells close to manured fields (Fig. 7). There is good agreement between nitrate concentrations and nitrate fluctuations in soil profiles and in shallow ground-water tubes. In some profiles and ground-water tubes in lenses with fine textured soils no nitrate is found. This may be a result of denitrification.

Discussion

The most urgent measures to be taken are to avoid surplus fertilization and to improve manure utilization. As the first step, our intention was that the measures would not cause economic losses.

Manure application in autumn and in winter is most hazardous on these coarse textured soils. More manure ought to be spread during spring operations. For that reason the storage capacity for manure has been extended to 10-12 months on the three most important farms at Jonstorp, Hässlås and Dettan during 1983.

New production plans were developed in the spring of 1983 in co-operation with the farmers. These plans aim at fertilization according to existing recommendations in order to improve fertilizer utilization by the crops.

Besides more appropriate fertilization practices it is also most urgent to keep the fields "green" as far as possible during autumn and winter and thereby avoid bare soil, which is most sensitive to nutrient leaching. The farmers are therefore recommended to grow more autumn cereals and pasture.

High amounts of nitrate are often found in soil profiles after growth of spring cereals, a crop type which has become more and more common in Swedish agriculture. However, by sowing a catch-crop together with the main crop, a spring cereal, nitrate can be tied up in organic matter and leaching avoided (Table 1). A more frequent use of catch-crops especially together with spring cereals can in humid regions be an effective measure to reduce nitrate leaching and even to control erosion. A development of such a modified growing system might also have other advantages such as increasing organic matter content.

Use of a catch-crop together with spring cereals is studied in pilot-scale within the project.

As a further step nitrogen fertilization will be reduced by 30 per cent from the spring of 1984 at the recharge area of Jonstorp and at one of the private wells.

Preliminary economic evaluation indicates that measures within agriculture probably are considerably cheaper and safer in the long run than deep drilling, use of ion exchangers, or development of new wells. The main problems are the difficulty in confirming the recharge area and the long turnover time of the water reservoir in most cases.

This year we also hope to clarify the legal aspects of taking measures within agriculture.

The intention of this research is primarily to produce enough knowledge to formulate recommendations about how to protect ground-water reservoirs of interest for municipal and private water supply from nitrate pollution by farming activities. Another purpose is to find effective and practical measures for widespread use in agriculture. However, some measures can be taken today.

Action Proposal

In municipal water supply large ground-water reservoirs are often utilized. Because of the thickness and texture of the unsaturated zone, the amount of percolating water and the turnover time of water in the ground-water reservoir, agriculture management one year may not be fully reflected in water quality until several years later. This means that many water supplies have not yet reached maximum nitrate concentration reflecting the increased fertilizer use during the seventies. However, it also means that the corresponding time lag exists for preventive measures taken within the recharge area.

In this perspective all municipal water supplies and areas of potential interest for ground-water extraction, with dominating arable land in the recharge area, are proposed for the following actions:

- An inventory is made of all farms in the recharge area. Production plans are created to avoid surplus fertilization and to improve the use of manure.
- On animal farms spreading of manure outside the recharge area is highly recommended. If that is impossible storage for one year's production of manure is arranged.
- Farmers are recommended to increase the growing of autumn grain and pasture but also to grow special "catch-crops".
- In regions where preservation of ground-water quality is particularly urgent water supply authorities should consider negotiation with farmers about further reduced fertilizer use and possibly a yearly renumeration to compensate for yield reductions.

Acknowledgement

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