Nordic Hydrology, 1979, 171-190

Deterioration in the Water Quality of Groundwater in Some Municipal Water Extraction Plants in Finland

Pertti Lahermo and Jouko Parviainen
Geological Survey of Finland, Otaniemi and National Board
of Waters, Mikkeli

In this study the changes in the quality of groundwater are described on the basis of material collected at some groundwater extraction plants situated mainly in urban areas. The causes of the marked increase in the content of dissolved solids are evaluated from the 1960s onwards.

Introduction

The first municipal groundwater works in Finland were constructed towards the end of the 19th century and at the beginning of this century. Most of these early well fields were built in the sparsely populated outskirts of towns, but have since been surrounded by expanding urbanization. This development as well as changes in groundwater regime owing to increased water exploitation have affected the quality of the groundwater. This paper describes the changes in water quality in the groundwater extraction plants of Helsinki, Turku, Tampere, Mikkeli, Porvoo, Hartola, Joensuu and Kokkola. In addition brief mention is made of some other case studies (Fig. 1).

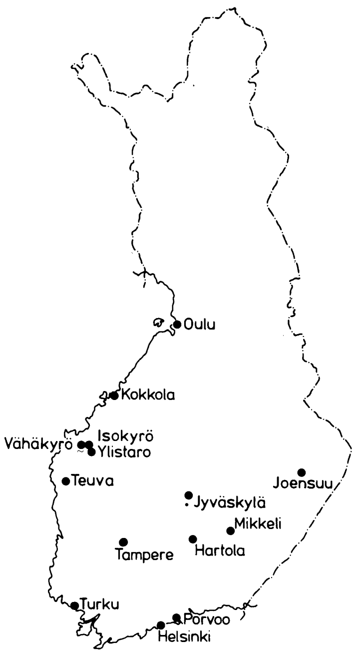

Fig. 1. The location of the groundwater extraction plants described.

Case Studies

Helsinki: Tattarisuo and Vuosaari

Four minor groundwater extraction plants are in use in Helsinki. Groundwater accounts for less than one per cent of the total municipal water consumption. Tattarisuo, the site of the water extraction plant lies about 10 km north of the city centre. The plant has been constructed on a flat esker at the foot of some cliffs and at the edge of the mire. Much of the sand and gravel above the groundwater table has been excavated, and the gravel pits either refilled or levelled. The motorway leading from Helsinki to the North, which is one of the busiest in the country, has been built on the upstream side of the well field; there are also numerous local roads nearby.

The electrolyte contents, total hardness and alkalinity of the groundwater increased conspicuously in the late 1960s when the motorway and other roads passing the well field were built (Fig. 2). There is no correlation between the development of water quality and the large fluctuations in pumping rate in the 1960s. The amounts of groundwater extracted have been much lower in the 1970s

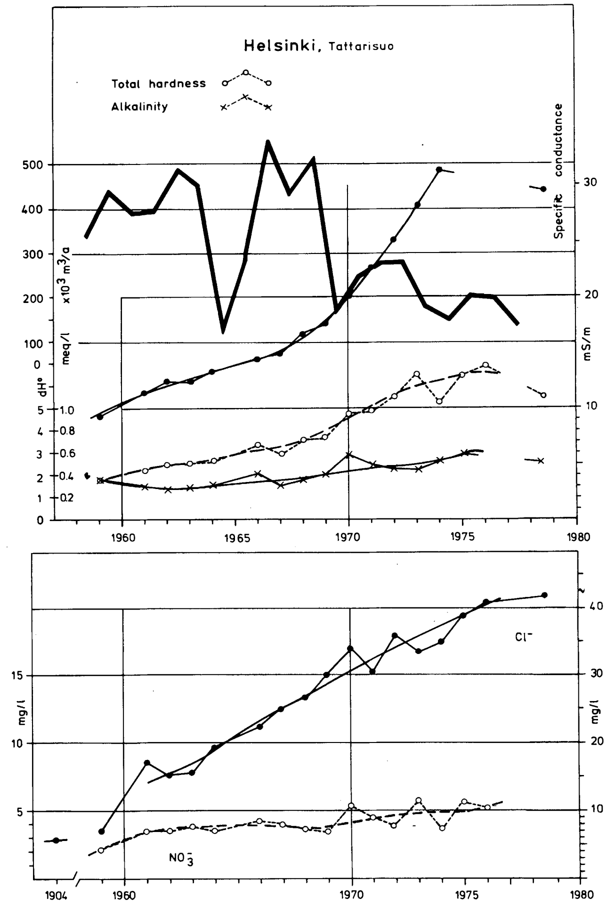

Fig. 2. The development of total hardness, alkalinity and specific conductance values (upper graph), and nitrate and chloride contents (lower graph). The heavy line indicates the amounts of water pumped. The first chloride determination was made in 1904 on water from a spring near the plant. The spring has since dried up. The values are single or the annual arithmetic means of 2-3 determinations.

whereas the dissolved solid contents have been notably higher. The chloride contents have also markedly increased, whereas the nitrate contents show little change.

This is because of the overall increase in urban population as a result of extensive building programmes. The large excess of chlorides over nitrates suggests that the bulk of the external matter entering the groundwater originates from traffic and, particularly, from the defrosting salt put on roads. The increase in the Cl^-/NO_3^- ratio in the 1960s adds weight to this point of view (Fig. 3). In the

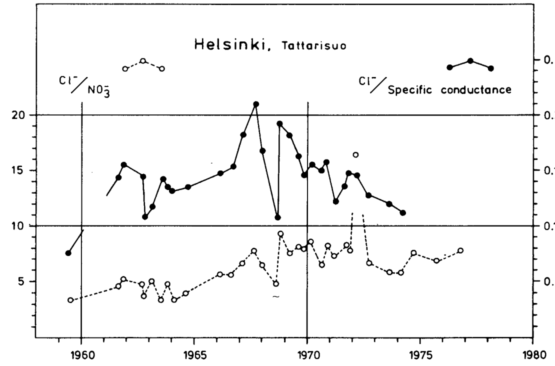

Fig. 3. The ratio of chloride contents to nitrate contents and specific conductance values respectively as function of time.

1970s the chloride contents have decreased in relation to specific conductance, i.e. the amount of dissolved electrolytes. The ratio referred to correlates strongly with the amounts of groundwater pumped (cf. Figs. 2 and 3). At the low pumping rates employed in the 1970s the ratios have decreased. This may be because of the higher electrolyte contents of the groundwater, whose retention time is longer during a low extraction rate. It is also possible that the recovery in microbiological activity in the soil after road construction affects the growth of total electrolytes and hardness. Because of the growth and destruction of organic material, more carbon dioxide enters the soil and groundwater and thus carbonate and silicate minerals are leached more effectively. The iron contents have been below 1.5 mg/l, however, fluctuating considerably.

The suburb of Vuosaari, about 15 km from Helsinki, has three groundwater extraction plants; two of them, Hautala and Huvilamäki, works are discussed here. They are located at the edge of a flat glaciofluvial esker bordered by outcrops of Pre-Cambrian basement and clay beds overlying sand and gravel deposits. The main recharge area is nowadays the site of old gravel pits, busy roads, large apartment blocks and factories.

As at Tattarisuo, the contents of dissolved solids increased markedly at both Hautala and Huvilamäki groundwater extraction plants (Fig. 4). The chloride, sulphate and carbon dioxide concentrations also increased, whereas those of nitrate showed little change. Nitrogen compounds occurring in reduced form were below the limits of detection. At Hautala plant reducing conditions are reflected in the increase in iron contents, which was why pumping was stopped in the middle of the 1970s.

The low concentrations of nitrogen compounds indicate that the strong increase in dissolved solids is not mainly caused by sewage pollution. Rather, the chlorides

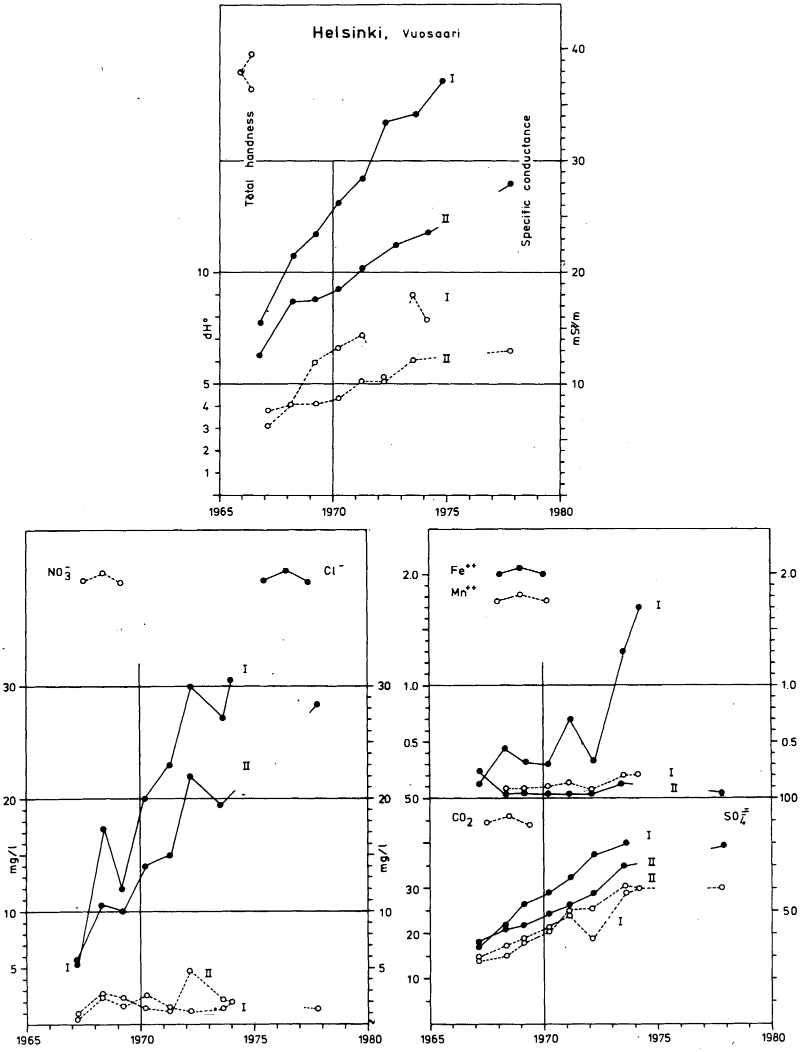

Fig. 4. The development of total hardness and specific conductance values (upper graph), chloride and nitrate contents (left-hand graph), and iron and manganese contents (right-handgraph). I, Hautala; II Huvilamäki groundwater extraction plant.

refer to the effect of marine salts percolating from the nearby sea or possibly to technical contamination, e.g. the effect of defrosting salts. The marked increase in the sulphate content is not easily explained, put it may be partly attributed to local sulphur dioxide fallout from the air. This cannot be because marked increases have not been noted elsewhere, e.g. at Tattarisuo.

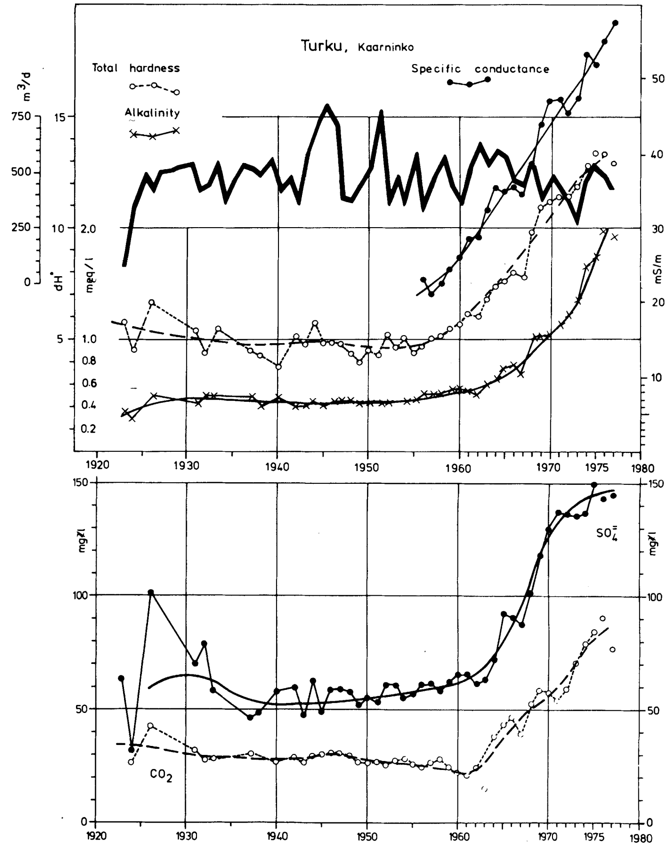

Fig. 5. The development of total hardness, alkalinity and specific conductance values (upper graph), and sulphate and carbon dioxide contents (lower graph). The heavy line indicates the amounts of water pumped.

Turku: Kaarninko

The Kaarninko groundwater extraction plant in Turku was built in 1902 and is located about 3 km southwest of the town centre on an esker surrounded by clay deposits and groups of outcrops. There are extensive gravel pits south and north of the well field. Some of them have now been filled with waste soil. The Turku-Helsinki road, which was widened into a motorway a few years ago, passes through the well field.

Gravel excavation, the subsequent filling of the pits, the construction of roads and the increasing traffic in the infiltration area are all reflected in the marked increase since the early 1960s in electrolyte contents, total hardness, alkalinity, carbon dioxide and sulphate contents (Fig. 5). The same trend is seen in the chloride contents, which, before the peak in the 1960s, had increased very little

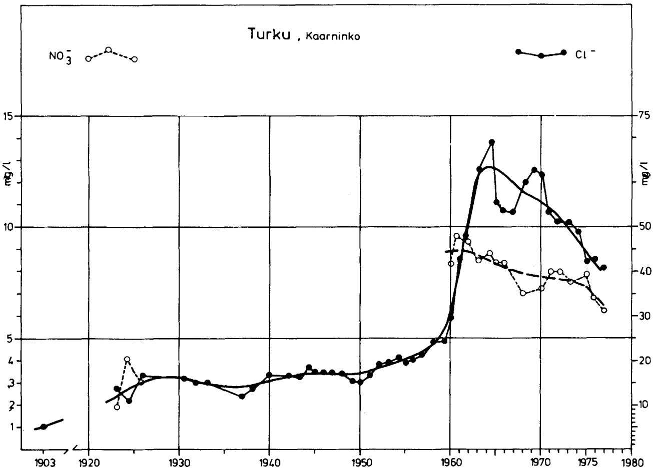

Fig. 6. The development of nitrate and chloride contents.

since 1903 (Fig. 6). The peak may be attributed partly to the excavation of gravel close to some wells and to the saline snow dumped in the pits during that period. Since the peak, the chloride contents have decreased considerably, possibly because waste soil is no longer dumped. Likewise, the nitrate contents have decreased somewhat since the peak.

The iron contents have fluctuated (0.03-0.20 mg/l) more than those of manganese, which occasionally have even exceeded the former (0.07-0.13 mg/l). The average decrease in iron contents may refer to oxidizing conditions in the surficial part of the groundwater zone as a result of extensive gravel excavation.

Tampere: Hyhky

The Hyhky groundwater extraction plant is situated 3 km from the centre, at the foot of the large Pispala esker. The surroundings are densely populated; the new motorway to Nokia passes very close to the well field, and there is a busy railway in the main recharge area. These polluting factors are exacerbated by the extensive excavation and filling operations in connection with the construction of the motorway that were carried out on the northern flank of the esker, near the shore line of Lake Näsijärvi. The water level of Näsijärvi is about 18 m higher than that of Lake Pyhäjärvi on the other side of the esker, where the well field of Hyhky plant is located. Thus, there is no doubt that some of the water extracted from the well field has infiltrated from Näsijärvi. This kind of natural recharge into the esker takes places evidently in the large Tahmela spring, and some other smaller ones that discharge their water into Pyhäjärvi at the southern flank of

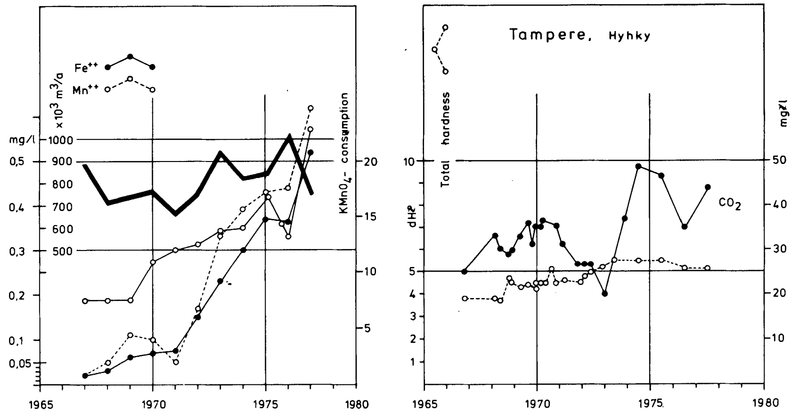

Fig. 7. The development of iron and manganese contents and $KMnO_4$-values (left-hand graph), total hardness values and carbon dioxide contents (right graph). The heavy line indicates the amounts of water pumped. In the picture on the left the values are the annual arithmetic means (of 12 to 46 determinations), as they are in the picture on the right from year 1973 onwards.

Pispala esker 1 km to the east of the well field.

In the 1970s, shortly after the construction of the new motorway, the iron and manganese contents and the $KMnO_4$ consumption values increased to such a level that the plant had to be closed a few times (Fig. 7). The amount of water pumped has not changed conspicuously; thus, the reasons for the increase in the contents have nothing to do with hydrodynamical changes in the groundwater. The general opinion is that the deterioration in the quality of the groundwater is due to infiltrated surface water from the lake into the aquifer. Underwater earth removal on the shore has broken the impermeable bottom sediments and caused large-scale infiltration from the lake into the esker. Surface water containing more organic material than groundwater caused reduced conditions in the aquifer, as is shown by the increased chemical oxygen demand (COD) of the water ($KMnO_4$ consumption in Fig. 7). As a result, the CO_2-contents also increased, and this in turn produced conditions that favoured the dissolving of iron and manganese (Fig. 7). Total hardnesss and total dissolved electrolyte content increased only slightly (from 18-20 to 20-23 mS/m).

Mikkeli: Hanhikangas

The Hanhikangas groundwater supply plant in Mikkeli went into operation in 1911. It is situated by a rather broad and undulating esker to the north of the town. In spite of its urban location, the quality of the water changed little before the mid-1950s (Fig. 8). Because of abnormal high iron contents in the water of

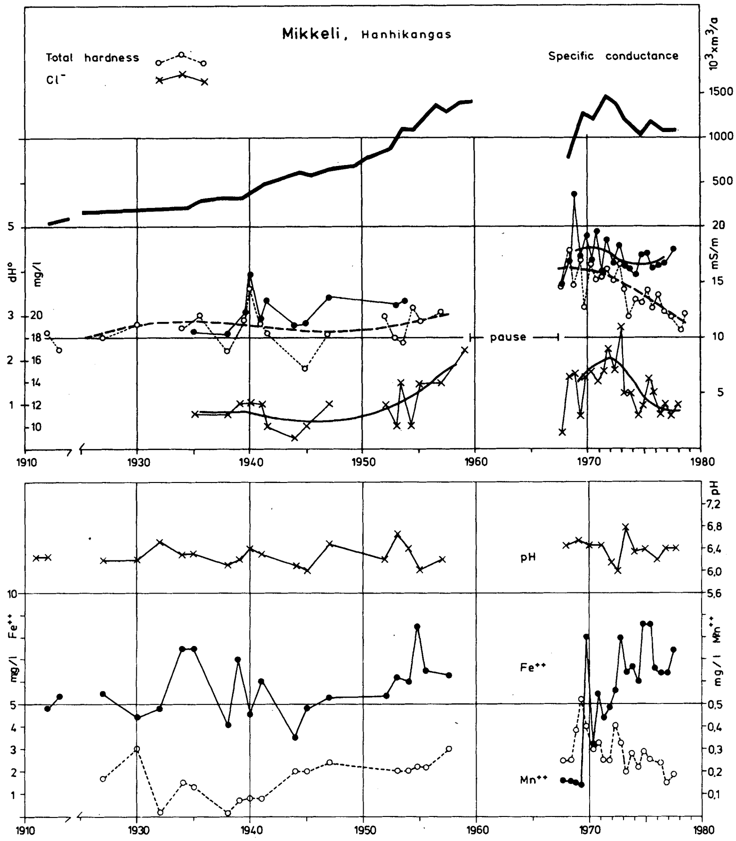

Fig. 8. The development of total hardness and specific conductance values and chloride contents (upper graph), and iron and manganese contents and pH values (lower graph). The heavy line indicates the amounts of water pumped.

groundwater plants in Central Finland, the Hanhikangas plant was shut down in 1959-1968. The variations in iron contents depend on the amounts of water pumped and the season. In addition, the concentrations varied from well to well (cf. Jynkkä).

When the plant was started up again after the shut-down the contents of dissolved solids were higher, probably because of building operations and growth in the population in the intake area during the 1960s. Another reason may be that the quality of the water deteriorated when the safe yield of the aquifer was exceeded.

Before the mid-1970s the contents started to decrease, mainly because of the lower pumping rate and the artificial recharge of surface water in a basin a little more than 1 km to the north. The same trend is reflected in the chloride and manganese contents (Fig. 8).

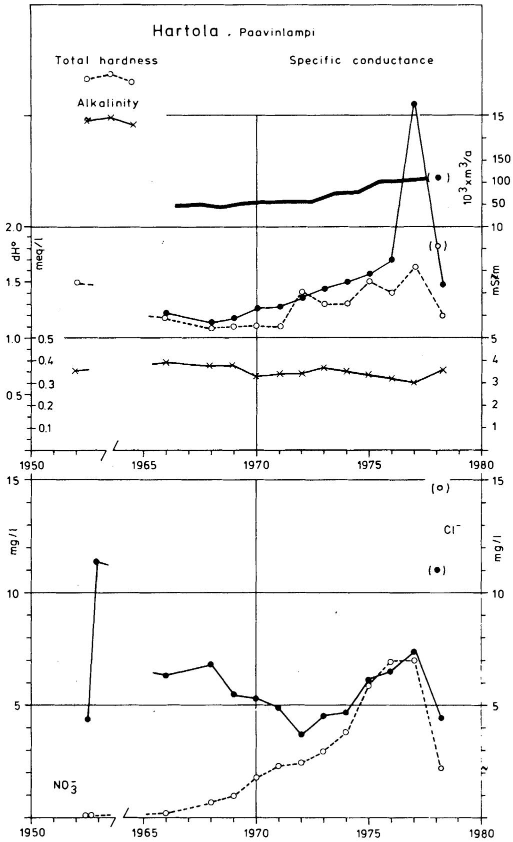

Fig. 9. The development of total hardness, alkalinity and specific conductance values (upper graph), and nitrate and chloride contents (lower graph). The determinations in brackets are for the nearby test pumping mentioned in the text. The heavy line represents the amounts of water pumped.

Hartola: Paavinlampi

The water supply of Hartola is based on groundwater extraction from the extensive esker nearby. The wells are located in a deep kettle occupied by Paavinlampi, a small lake 1 km to the north of the town, which lies in the southern part of the catchment area. These conditions explain why in the 1970s the dissolved solids, and the nitrate and chloride concentrations increased altogether in conformity with extending exploitation (Fig. 9).

Although the contents of dissolved solids have increased, they are still low, indicating comparatively intact conditions. In diluted waters of this kind, the very smallest addition of electrolytes causes visible changes in the water chemistry. The reasons for the changes are pollution due to growth in population and such factors as leaking sewage pipes, which are especially indicated by the growing trend of nitrates.

At the beginning of 1978 test pumping was carried out in a deep kettle in the same aquifer as the Paavinlampi plant but 200 m away from it. The amount of water pumped ranged from 1,500 to 2,000 m^3 per day. As at the start of the Paavinlampi water works, the contents of dissolved electrolytes and chlorides were rather high (Fig. 9). A decrease in the first high concentrations when test pumping or water intake has gone on for some time is a common feature; this is discussed later (cf. Palokka). The pumping caused some changes in the groundwater regime, so that later the nitrates and chlorides contents at Paavinlampi water works also decreased.

Porvoo: Linnanmäki

The Linnanmäki groundwater extraction plant in Porvoo was built in 1922 in the vicinity of the old town centre on an esker that follows the valley of the river Porvoo. The esker is largely covered by clay deposits. Linnanmäki, the site of the water works, is a fairly high glaciofluvial hill.

There has been a marked increase in the pumping rate during the 55 years of operation; this has been particularly noticeable since the mid-1960s. As a result, the groundwater table at Linnanmäki has dropped by a couple of metres, and the ground water has started to flow from more distant deposits overlain by clay deposit. This is reflected in the increase in the electrolyte content of the water (Fig. 10). In the past a number of wells have been constructed at the Linnanmäki water works. The quality of water varies conspicuously from well to well and to such an extent that the analyses are not fully comparable with each other; nevertheless, there is no doubt that a general trend exists. The determinations presented from year 1975 onwards refer to well 5.

Since the groundwater reservoir is loaded to the extreme and the sustained yield is exceeded, more old groundwater and relict marine salts in clay, in sand deposits overlain by clay and in fractures of bedrock enter the groundwater intake. The principal reason for the sharp increase in electrolyte content, however, is the inflow of recent sea water into the aquifer. Sea water occasionally flows up the river Porvoo as far as Linnanmäki from the near-by coastal inlet. Salt enters the groundwater when the river water infiltrates into the esker; this is reflected in the high chloride peak (Fig. 10). The population around Linnanmäki has not grown much during the last few decades; thus, human pollution has caused no more than a slight increase in salinity in the groundwater. This is also demonstrated by the low level of inorganic nitrogen contents, e.g. of NO_3 contents, which for several years have remained practically constant or have even decreased. Because of the marked reducing conditions, the contents of ammonia (0.2 – 0.4 mg/l) are higher than those of nitrates.

To restore equilibrium and to improve the quality of the groundwater, surface water from the river Porvoo is now being infiltrated into the aquifer through the

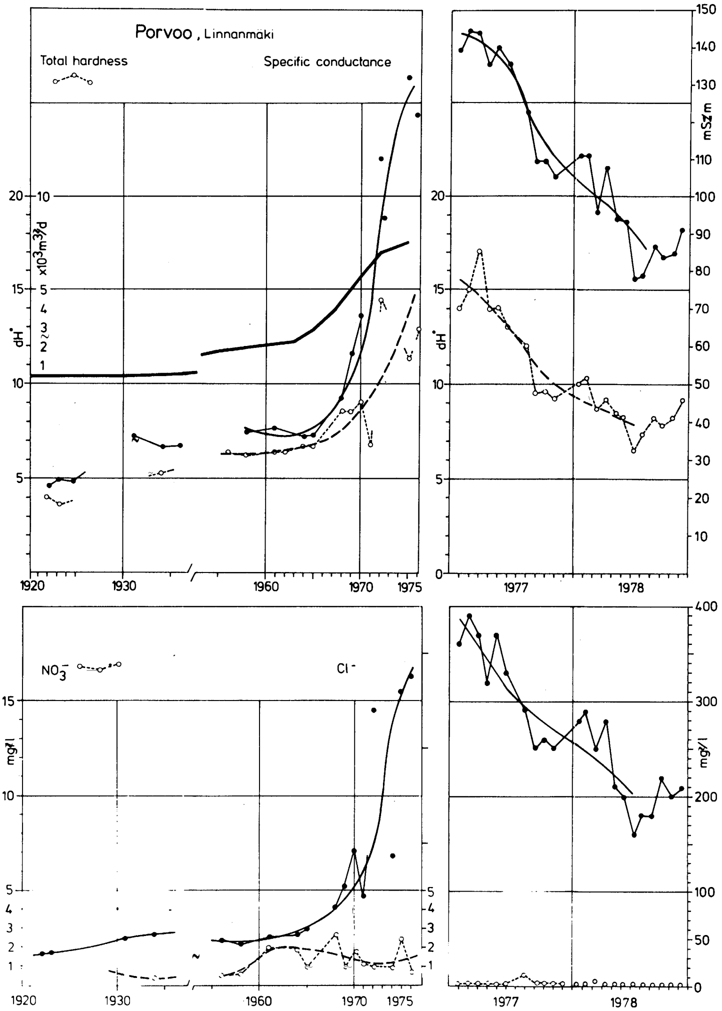

Fig. 10. The development of total hardness and specific conductance values (upper graph), and nitrate and chloride contents (lower graph).

esker that rises above the clay cover 500 m north of Linnanmäki. The amounts of water recharged from the river Porvoo have averaged 2,000 m^3 per day, which is about one third of the groundwater amounts pumped. Hence, in 1977 and 1978 the total hardness and the chloride contents started to decrease (Fig. 10).

The iron and manganese contents have also decreased as a result of artificial recharge. Nevertheless, the only effective way of restoring the quality of the water to an acceptable level is to reduce the rate of pumping so that equilibrium is restored between the natural groundwater recharge and the groundwater discharge.

Some Aspects of Iron and Manganese

In the case studies the development of iron and manganese have been briefly discussed (cf. Hyhky and Hanhikangas). These elements are important not only for evaluating the suitability of water for drinking purposes but also from a scientific point of view. Hence some case studies, especially those describing the behaviour of iron and manganese, are referred to.

Kokkola: Patamäki

The Kokkola groundwater extraction plant lies about 1.5 km from the centre of the town in a flat sand and gravel area. Nearby there are some gravel pits, a railway line and a busy road leading from Ykspihlaja harbour. From the mid 1960s to the beginning of the 1970s the dissolved solid contents increased conspicuously (Fig. 11). At the beginning of the 1960s the average values of total hardness were 3.5 German degrees; in the 1970s they have risen to a level of 6-7 degrees. The large variations were partly due to meteorological factors, which have a strong effect on groundwater that occurs near the surface. The CO_2 contents have also increased markedly; hence the pH values have dropped and the iron and manganese contents have increased (Fig. 11). High contents of these elements are a common feature in the coastal areas of the Bothnian Sea. This is explained partly by the low pH level, which is a result of sulphuric acid from oxidized sulphides in the marine silt and clay deposits and partly by the strongly reduced conditions in aquifers overlain by clay, silt and peat. Consequently, the sulphate

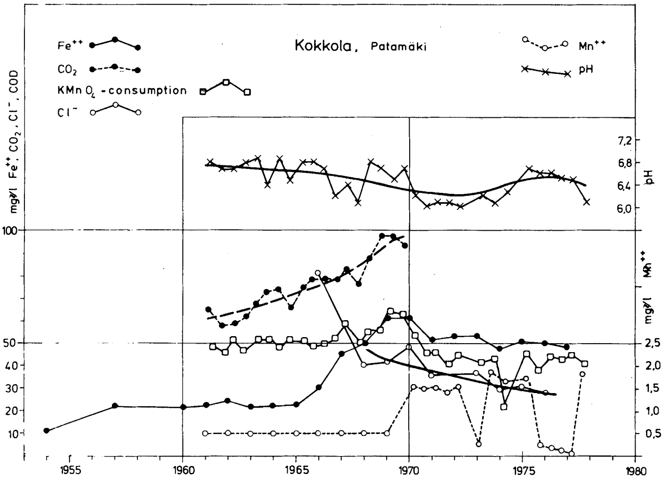

Fig.11. The development of iron, manganese, CO_2 and chloride contents, and the $KMnO_4$ consumption and pH values.

contents are comparatively high, varying within the range of 145 to 175 mg/l. However, only a very slight increase is found as a function of time.

The exceptionally high contents of iron and manganese in groundwater are the crux of the problem in operating the Kokkola purification and water works. As to the extremely high iron contents, the conditions prevailing in the aquifer must be highly reduced; consequently, some of the dissolved total nitrogen occurs as ammonium (an average of 0.4 – 0.8 mg/l) and there are very small amounts of nitrate. The reason for the increase in CO_2 can only be speculated on; it cannot be the result of human pollution, as is indicated by the unmistakeable reduced trend of the chloride contents.

Joensuu: Jynkkä

The groundwater extraction of the town of Joensuu is concentrated on an esker sequence, which is cut by the river Pielisjoki at Jynkkä, about 5 km to the north of the town centre. Although the groundwater table coincides with the river there is no completely free hydraulic connection between the aquifer and the surface water body. The well field is located on the shore where in a natural state there has been some discharge into the river (springs and seeps).

During the last twenty-five years the marked growth in water intake has led to an increase in iron contents although the total dissolved solids have remained nearly constant. Initially there was only one well but in the 1960s the iron contents rose so high that the construction of additional screened wells became essential. During regulation works carried out on the Pielisjoki, the water level dropped by 1.0 to 1.5 m in 1971. The corresponding decline in the groundwater table in the well field close to the shore caused an increase in iron contents (from 0.5 to 1.5 mg/l). In the 1970s still more wells were constructed; the safe yield was exceeded, however, and the diluting of the concentrations was only temporary. The concentrations vary from well to well, and even in the same well during a single day. (Fig. 12).

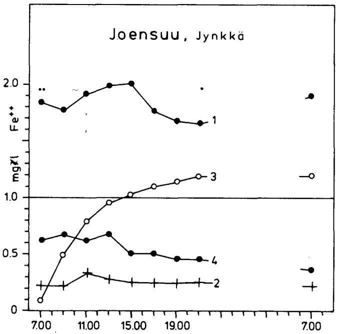

Fig.12. The development of iron contents in wells 1-4 during one 24-hour period (15-16.8.1977).

A special iron removal system was applied to solve the problem of iron at Jynkkä water works. The iron-rich groundwater (from well 1) is conducted to a nearby forested slope, where the running water gradually infiltrates into the soil. Most of the iron oxidizes and precipitates on the surface. The recharged groundwater is pumped from the original groundwater wells (wells 2, 3, and 4). These arrangements have eased the problem of iron; even so the quality varies largely in individual wells and as a function of time and the amount of water pumped.

Ylistaro, Isokyrö and Vähäkyrö

There is a small groundwater extraction plant (100 m^3 per day) about 7 km to the southeast of Ylistaro. It has been built on a flat cultivated agricultural field and derives groundwater from a confined aquifer covered by clay beds. The aquifer is recharged a few hundred metres from the wells, where is outcrops though the clay cover.

Despite large variations, a slightly rising trend is noticeable in the contents of dissolved solids. In the 1970s the total hardness has averaged 1.5 – 2.5 German degrees. Carbon dioxide contents are comparatively high (Fig. 13), whereas pH values have been reduced, occasionally down to below 6.0. Thus the contents of some elements, iron in particular but also manganese to some extent, have increased sharply during the present decade. Despite the low level of the average nitrate contents (0.5 mg/l), the slight increase observed indicates the effect of fertilization on the groundwater. The chloride contents are low (5 mg/l). The increase in the concentrations mentioned above may be attributed to the growth in water intake.

The groundwater extraction plants of Suolanen at Isokyrö and Vedenoja at Vähäkyrö are located on a flat cultivated plain, where the groundwater occurs in sand and gravel deposits overlain by clay beds 3 to 6 m thick. In hidden eskers of this kind or other clay-covered glaciofluvial deposits increased water intake has a strong influence on iron contents (Fig. 14). This is true especially when the safe yield is exceeded.

Discussion

The examples given in the present study, as well as numbers of other cases, show that in densely populated areas the quality of groundwater has undergone marked changes in the past 20 year or so whereas until the 1960s the increase in electrolytes had been only slight. This is so, even if changes in analytical methods, infrequent and irregular sampling, the construction of additional wells and seasonal quality fluctuations are taken into account.

In all the examples referred to, environmental conditions have changed to some

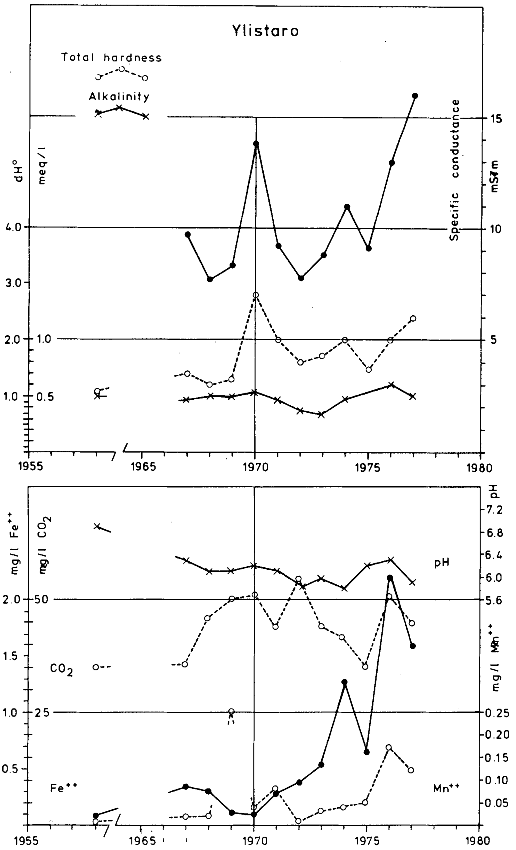

Fig.13. The development of total hardness, specific conductance and alkalinity values (upper graph), and iron, manganese and CO_2 contents and pH values (lower graph).

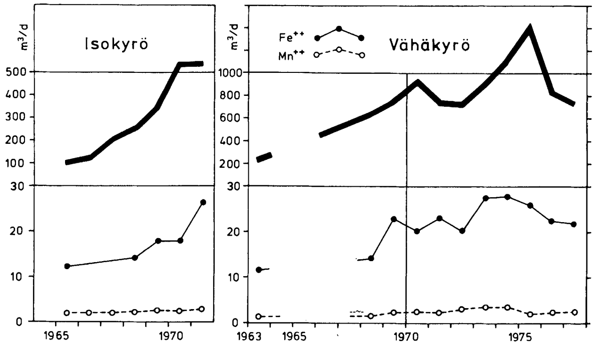

Fig.14. The dependence of iron and manganese contents on the amounts of groundwater pumped. For Vähäkyrö, the determinations are arithmetic means from three closely spaced wells. Only one analysis annually.

extent. If conditions have remained more or less intact and the pumping rates have not exceeded natural recharge, the chemical quality of groundwater has been practically constant (Fig. 15, lower graph).

In some cases the amounts of electrolytes in groundwater may even decrease when the rate of water exchange in the aquifer is increased and younger water is received by the intake (Fig. 15, upper graph). This phenomenon is most likely to occur when the wells are in large unconfined aquifers not bordered by clay and peat deposits. Sometimes chemical components in groundwater are at a reasonably high level when test pumping or intake from the aquifer starts but decrease as the pumping continues (cf. Paavinlampi).

The general increase in electrolytes is partly due to increased water exploitation. The positive correlation between the quantity of water pumped and the contents of dissolved electrolytes is most marked in eskers in low-lying areas and partly or wholly covered by clay beds (cf. Ylistaro), and in other aquifers overlain or bordered by clay or peat beds, especially in densely populated areas. When the groundwater table declines, the water percolates not only from the deeper horizons of the groundwater zone but also from more distant clay-covered confined deposits, and even from fractures in the bedrock. The intrusion of old more highly mineralized groundwater and, in coastal areas, of relict or even recent sea water, increases the electrolyte contents (cf. Linnanmäki). This is reflected particularly in extensive chloride and sodium contents.

As the groundwater is extracted from deeper and more reducing groundwater

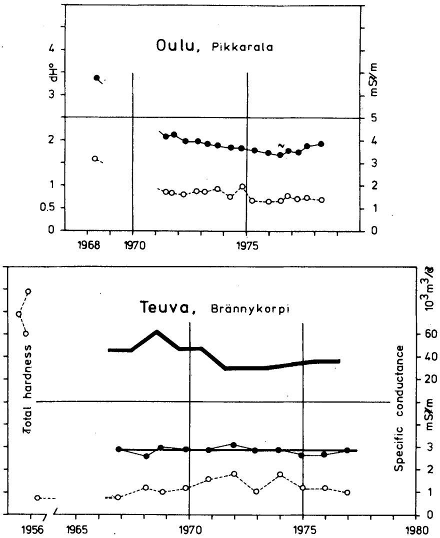

Fig.15. The development of specific conductance and total hardness values in two groundwater extraction plants. The heavy line indicates the amounts of water pumped.

zones, especially the iron and manganese contents increase in proportion to the increase in groundwater extraction. It is generally considered that when the pumping rate exceeds the safe yield or natural recharge of the aquifer, the iron and manganese concentrations begin to increase (cf. Isokyrö, Vähäkyrö). In this respect the behaviour of these elements is most susceptible to disturbances in the groundwater regime.

The development of nitrate contents at the Palokka groundwater extraction plant is particularly interesting. This plant is located 5 km to the north of Jyväskylä at the foot of a slope tilting towards the southern end of the lake Alvajärvi. The upper parts of the hill are covered by till deposits, and in some places the basement outcrops. The aquifer body on the lower slope of the hill is composed of sand layers partly overlain by silt deposits. The estimated daily groundwater resources of the acquifer are 600-700 m^3; at present, 300 m^3 are drawn daily.

The nitrate contents were high during test pumping but then started to decrease conspicuously (Fig. 16, cf. also Paavinlampi). After the completion of the well field they continued to decrease slightly. This trend may have been due to earlier agricultural activity, in the course of which nitrogen compounds were deposited in the soil. Nowadays the recharge area is largely occupied by an urban residential area. Increasing pumping rates have caused more effective leaching in the recharge area. Another reason for the trend may be the dilution of concentrations as a result of mixing with pure groundwater flowing from more distant areas of the aquifer. From 1974 onwards, nitrogen-poor groundwater from Kirri well field, 1 km to the north, has mixed with groundwater from Palokka and notably reduced the more recent concentrations.

Even so, the main reason for the change in the quality of groundwater in urban areas is the growth of population and the associated polluting factors, e.g. leaking sewage pipes, intense gravel excavation often in the immediate vicinity of well fields, the refilling of gravel pits with dirty soil or saline snow, building works, particularly the construction and maintenance of roads, and traffic. These changes are reflected in increased amounts of electrolytes, total hardness, $KMnO_4$ consumption, chloride, nitrate, calcium, and potassium contents.

Asemanseutu groundwater extraction plant is an example of observed groundwater pollution. The well field is located in a built-up area, near Orivesi railway station, at the terminal part of an esker sloping towards a lake partly covered by silt deposits. Half a kilometre upstream there is an old abandoned gravel pit which had served as a store for defrosting salts for the roads. Furthermore, near the wells a septic underground container was leaking into the ground. Thus pollutants entered the ground from overall human activity, but especially from the two sources mentioned. As a result the concentrations of nitrates and especially of chlorides were high (Fig. 17). Alterations in concentrations were marked because of variations in polluting activity and the rate of leaching and infiltration in the

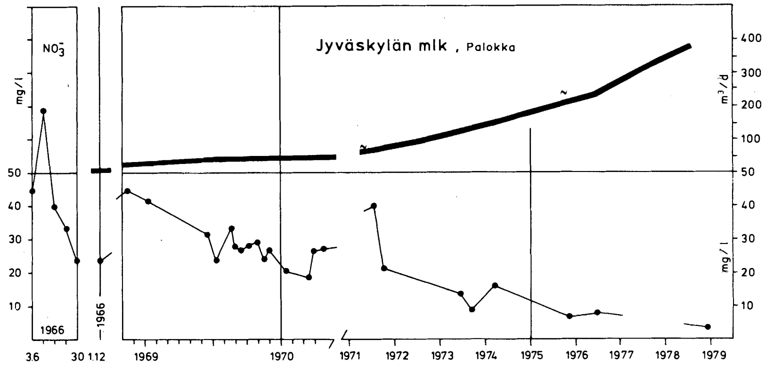

Fig.16. The development of nitrate contents. The heavy line indicates the amounts of water pumped.

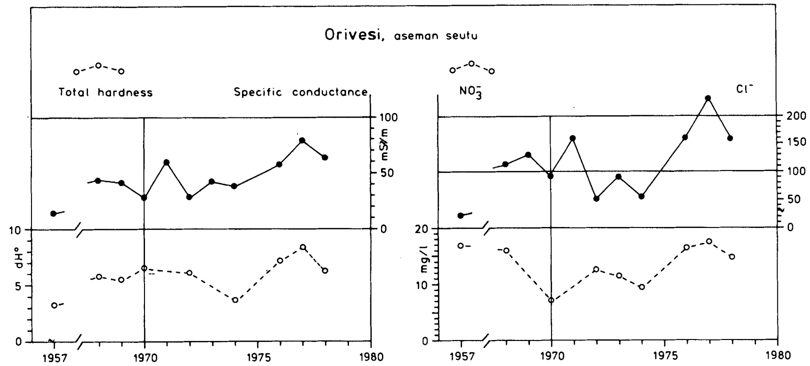

Fig.17. The development of total hardness and specific conductance values (left-hand graph), and nitrate and chloride contents (right-hand graph). The values are single or annual arithmetic means of two determinations.

recharge area. Because of severe bacterial contamination the plant was shut in 1974-75.

The amount of chlorides discharged annually can be calculated from the amount of water pumped and the chloride contents. Calculated as NaCl the amounts discharged are astonishingly large ranging from 10 to 15 tons per year. Because chlorides occur in some tenths of a milligramme in natural groundwater, they are derived nearly completely from pollution.

Human activity affects indirectly the biological state of the soil. Large-scale earth removal reduces CO_2 production by destroying biologically active soil, and thereby diminishes the leaching capacity of soil moisture and groundwater. Also the growth of SO_2 emissions introduced into one soil plays a key role in increasing eluviation. This may be an important reason for the increase in sulphate contents at Vuosaari and Kaarninko.

In spite of the increase in electrolyte contents, the limits set by the National Board of Health or international standards have seldom been exceeded. Only a few of the groundwater extraction plants have had to be closed as a result of pollution. In the cases referred to, the nitrate and chloride contents were far below the limits set. Thus, even though the ability of the soil to purify groundwater seems to be good, groundwater protection should not be neglected. The cases described show how rapidly dissolved solids increase in urbanized areas; in some plants this may lead to concentrations in excess of the standard self-purification capacity of the ground.

Acknowledgements

The authors are indebted to the municipal Water Works concerned, to the building offices and Water Districts of the National Water Board for the analytical data presented in this study, to Mr. Erkki Herola and Markku Putkinen for collecting and treating the data, to Misses Mirja Törmälä, Hilkka Haavisto and Tarja Ikonen for drawing the graphs, and to all other persons who participated in the present work.

References

Cole, J. A. (1974) Groundwater Pollution in Europe. Proceedings of a Conference organized by the Water Research Association in Reading, England, September 1972. Water Information Center, Inc. Port Washington, New York, 547 p.

Lahermo, P. (1970) Chemical geology of ground and surface waters in Finnish Lapland. Bull. Comm. Geol. Finlande 242. 106 p.

Todd, D. K., and Orren McNulty, D. E. (1975) Polluted Groundwater. A Review of the Significant Literature. Water Information Center, Inc. Huntington, New York. 179 p.

Received: 26 January, 1979

Address:

Pertti Lahermo,
Geological Survey of Finland,
SF-02150 Otaniemi,
Finland.

Jouko Parviainen,
National Board of Waters,
Mikkeli District Office,
Mikkeli,
Finland.