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GROUNDWATER QUALITY IN THE NETHERLANDS - COLLECTION AND INTERPRETATION OF DATA

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ABSTRACT

In The Netherlands many groundwater quality data are available. At the same time, much research is being done on groundwater quality and groundwater pollution. This paper deals with problems of interpretation of groundwater quality data related to hydrogeological conditions, location of boreholes and sample handling. Attention will be paid to the quality of groundwater in The Netherlands.

INTRODUCTION

Groundwater is the principal source for the supply of water for both domestic and industrial use in The Netherlands. In 1976, almost 1,000 million cubic meters of groundwater were abstracted for these purposes, compared to some 450 million cubic meters of surface water. About 70% of all groundwater pumping stations in The Netherlands are withdrawing groundwater in upper, sandy aquifers. Even 50% of these pumping stations have their wells in phreatic aquifers. Hence it will be clear there is a real risk for contamination by human activities, of groundwater in the catchment areas of pumping stations. For this reason, groundwater is, of old, being monitored by public waterworks. Moreover, groundwater is being monitored by private and government institutes for many purposes. The most comprehensive public databank for groundwater quality is located at the National Institute for Water Supply. It contains data of about 20,000 groundwater samples. However, only few data on trace elements and organic micropollutants are available. Nevertheless, the available data indicate not only a gradual deterioration of groundwater quality, but also a wide distribution of micropollutants.

In some cases the level of recently observed pollution was such that domestic supplies had to be interrupted. For these reasons it is clear that the monitoring of groundwater quality is necessary, in order to detect pollution and to prevent use of contaminated groundwater for public water supply.

INTERPRETATION OF GROUNDWATER QUALITY DATA

Natural groundwater quality varies widely, even at short distances, depending on

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hydrogeological conditions and type of soil. Table 1 provides some insight into these variations. The high bicarbonate concentrations in peaty areas and the high chloride contents of marine groundwater are striking. In phreatic, sandy aquifers there can be significant differences in hardness and bicarbonate content. Often these values in infiltration areas are very low. Downstream hardness gradually increases. In fact, many times it is possible to distinguish between infiltration and seepage areas by hardness and bicarbonate content, on the condition that sufficient data are available.

Many data are available on groundwater discharged at groundwater pumping stations. Nevertheless, it is not always possible to derive the trend of groundwater quality from these data. Often trends in quality of discharged groundwaters can be partly derived from changes in the catchment area of a pumping station. In that way, the trend of quality of discharged groundwater at pumping station 'De Pol' can also be explained (figure 1). From 1938 till 1960 the percentage of soil in the catchment area being used for agricultural purposes gradually increased by enlargement of the catchment area from zero to 75%, while the non-developed area decreased (fig. 2). After that period this ratio remained constant, thus explaining the change in trend in 1960. Before 1960 the trend was caused by a shift in soil use in the catchment area due to enlargement of this area, as well as by a gradual deterioration of groundwater quality in the several areas itself. After 1960, this shift in soil use can mainly be explained by deterioration of groundwater quality. Another example is given in fig. 3. In the groundwater pumping station Holten some wells are deriving their water from uncultivated infiltration areas with low ion concentration in the groundwater; other wells withdraw their water from aquifers below soil used for agriculture (fig. 3a) or from deeper strata with much higher ion contents. The latest is illustrated by fig. 3b. Wells in the centre part of the pumping station are withdrawing their water from a deeper more fine grained part of the same aquifer with a higher HCO_3^--content. Quality of withdrawn groundwater varies with the withdrawal schedule of the pumping station.

As indicated before, there is a close relationship between soil use and groundwater quality, especially in sandy, phreatic aquifers. Some results of statistical analysis of data available from monitoring wells are given in table 2. As expected, the highest ion concentration in groundwater can be found in areas with the most intense human activities. On the other hand, it has to be kept in mind that there is also, as mentioned before, a relationship between some parameters and type of soil. Statistical analysis of groundwater quality data clearly indicates a gradual deterioration of groundwater quality, especially for Cl^- and SO_4^{2-}, even in uncultivated areas (fig. 4). Apart from soil use this can be attributed to air pollution. Effects of industrial air pollution on groundwater quality in uncultivated areas are shown in fig 5.

Special computer programmes are developed to make statistical operations of large numbers of chemical analysis possible. Nevertheless, for a correct interpretation of data an individual approach of these data is also necessary. Only few data are available on trace elements, most of them from groundwater discharged at pumping stations.

Often, relatively high concentrations can be related to the presence of local waste disposal sites. Till now no direct relationship has been found with sources of a more diffuse nature. Some information on trace elements in groundwater in infiltration areas is given in table 3. Recent data on organic micropollutants indicate a wide distribution of these pollutants in groundwater, also in uncultivated areas, perhaps partly caused by rain. Analysis of water samples from the national monitoring network for groundwater quality shows that in 70% of all examined water samples organohalogen compounds have been detected in concentrations of more than 0.2 μg/l; in 16% of the samples the concentration was even more than 1 μg/l. A special problem in the interpretation of groundwater quality data is related to the question of how far a groundwater sample is representative for the overall situation in an aquifer. In fact, research indicates significant variations in groundwater quality in a horizontal as well as in a vertical sense, especially in the upper 10 to 15 meters below groundwater level, as shown in figure 6.

In general, data of groundwater, derived from more than 10 till 15 meters below groundwater level, can be, within certain restrictions, representative for part of an aquifer, thus making it possible to describe groundwater quality in an aquifer, sometimes even with isolines. The restrictions are determined by hydrogeological conditions, soil use and type of soil. Especially in shallow groundwaters, because of limited effects of dispersion, groundwater quality can vary widely at very short distances, thus requiring a thorough way of sampling and interpretation of data. For research purposes the use of mini-screens, making it possible to place many screens in a borehole, may be useful. In this way, even pollution transport can be traced as shown in figure 7. The use of a number of normal screens is limited by the size of the borehole. The use of long well-screens causes, besides normal mixing of different water qualities, short-circuit flow, thus influencing interpretation of data. Vertical flow of groundwater is shortcircuited by a screen due to the small resistance to the flow inside the screen itself, which is negligible in relation to the surrounding soil. The size of this short circuit flow is, as illustrated in table 4, proportionate to the cubed length of the screen.

In fact, at a research location near the dunes in an infiltration area with a constant horizontal permeability, groundwater withdrawn with a 15 meter long well-screen was mainly coming from the upper part of the well-screen, as could be detected by use of mini-screens in a nearby well. Using long screens also provides a possibility to intersect strata of varying permeability. This results in a preferential withdrawal of groundwater mainly from the more permeable strata as shown in figure 8, based on data from a research location near Uddel.

By drilling a borehole, groundwater and groundwater quality around the borehole will be disturbed. Dependent on hydrogeological conditions it takes considerable time, varying from some weeks till more than a year, before the original situation is restored. In this period sampling is useless, especially in case of considerable variations in groundwater quality. Figure 9 shows an illustrative example, based upon groundwater data collected near a waste disposal site. This figure also illustrates another phenomenon, especially of importance in case of groundwater monitoring in heavily polluted areas.

Drilling may cause pollution to be transported to deeper strata, possibly because of a temporarely shortcircuit flow, whilst direct contamination may be caused by a mantle tube or drilling fluid.

Other problems concerning the monitoring of groundwater quality near local polluting sources are caused by the limited flow tubes with polluted groundwater, surrounded by non-polluted groundwater, and so hampering detection of pollution. Problems in monitoring can be shown in figure 10, indicating the difficulty in choice of depth of screens when using normal well-screens. This figure also illustrates the use of tritium measurements for the dating of groundwater. It seems reasonable to assume that the increased tritium content in the groundwater at a depth of about 11 meters can be attributed to the higher tritium content in rainwater in the early 1960s as a result of atmospheric nuclear tests.

When monitoring groundwater near local polluting sources, special attention should be given to the possibility of density flow. With density flow, the vertical component can be considerably larger than under normal conditions, thus causing a deep penetration of pollution in the aquifer, already below the disposal site. For this reason, it is necessary to sample groundwater over the whole depth of an aquifer. Upstream pollution by all-sided groundwater flow coming from waste disposal sites and caused by the increase of the groundwater level in the site, requires attention for a correct choice of reference wells. As far as the many local polluting sources deteriorate groundwater quality, the development of quick field survey techniques seems useful.

Modern groundwater quality research requires, that much attention should be paid to the correct way of drilling, sampling and sample handling. This holds true for the risks of contamination of water samples, especially in the case of pollution of groundwaters with pollutants which already cause problems in very low concentrations. On the other hand, measures should be taken to avoid removal of pollutants from samples by adsorption, precipitation, degradation or evaporation. Especially when developing series of measurements in time, uniform directives for drilling and sampling procedures are necessary.

In addition to available groundwater quality data and existing local monitoring systems, the National Institute for Water Supply is currently engaged in establishing a basic groundwater quality monitoring network for the Ministry of Health and Environmental Protection. The objectives of the network are:

- to draw up an inventory of the present quality of groundwater to complement the information already available;

- to identify long-term quality changes;
- to provide the information required for an adequate groundwater management.

The establishment of the monitoring network is integrated with other planned or existing systems such as those for monitoring the quality of rainwater and water quality in the primary surface water system.

Some 400 monitoring stations are currently being positioned and equipped for sampling shallow groundwater. This is equivalent to an average monitoring ratio of one station per 80 square kilometers. A significant proportion of monitoring stations are located in key areas for public water supply, though observation wells are also placed in other areas, including those with brackish or saline groundwater. Furthermore location of shallow wells is related to soil use, type of soils and hydrogeological conditions, thus making it possible to relate groundwater quality and these parameters.

For the shallow monitoring stations, pulse boreholes are drilled to a depth of some 25 meters and partly subject to the geological condition of the substratum, screens are placed between 8-10, 12-24 and 23-25 meters below the surface. Efforts are made to ensure that at least the lowest screen is placed in a coarse sand aquifer. The top screen is placed a few meters below groundwaterlevel so as to allow for early recognition of future changes in quality. No samples are taken from the upper five meters of groundwater to eliminate effects which are too closely tied to the locality. The middle screen is included as a reserve (fig. 11).

During the initial phase, samples are normally taken annually from all monitoring points. More frequent sampling (up to 6 times per annum) is practiced during this period at a limited number of monitoring points. Furthermore, a number of monitoring points is selected for more extensive analysis of the abstracted groundwater.

It is to be expected that in due course there will be a number of differing analysis programmes and sampling frequencies which will be applied both horizontally and vertically, depending on the locations of the monitoring points. The basic analysis programme is given in table 5.

CONCLUSIONS

To interpret data of groundwater quality a thorough knowledge of local hydrogeological conditions is necessary. Special attention should be paid to a correct choice of the location of monitoring wells and well-screens. Drilling of wells causes a temporary disturbance of the original situation of groundwater quality and sometimes causes pollution of deeper strata. Consequently, after drilling is it necessary to wait some time before sampling; drilling through contaminated soils should be done carefully and should be avoided whenever possible. Statistical analysis of data is a useful tool in interpretation of groundwater quality data; however, an approach of individual data is also necessary. The use of long well-screens for monitoring wells should be avoided due to problems with mixing and shortcircuit flow. The use of mini-screens may be useful for research purposes. Special attention should be given to the manner of sampling and sample handling. Development of quick field survey systems seems to be useful.

TABLE 1

		Clay/Peat*		Dunes		Ice Pushed Ridges	
		6	6	33	40	23	38
		meter below groundlevel					
Cl^-	mg/l	72	7322	44	9250	14	10
HCO_3^-	mg/l	1300	876	312	298	13	159
SO_4^{2-}	mg/l	70	605	4	1450	8	8.8
K^+	mg/l	26	175	22	160	1.1	0.9
Ca^{++}	mg/l	34	1080	27	352	2.1	43

* 2 Wells at approx. 100 meters distance

TABLE 2

The effects of soil use on the quality of shallow groundwater (10 - 20 meters below the surface) in Eastern Brabant and Northern Limburg, (based upon 1400 analyses)

Parameter	Unit	Non-Developed land	Pasture land	Arable land	Built-up areas
Cl^-	mg/l	22	37	42	54
SO_4^{2-}	mg/l	34	41	54	91
NO_3^-	mg/l	1.9	1.3	10.4	30.0
HCO_3^-	mg/l	40	67	68	131
Na^+	mg/l	17	21	27	50
Hardness	mmol/l	0.59	0.91	1.13	2.07

TABLE 3

Heavy metals in groundwater (in μg/l)

	Veluwe	Dunes		Veluwe	Dunes
Cr	<1 - 5	0.6 - 1	Co	0.5 - 3	2 - 4
Cu	2 - 50	4 - 20	Cd	0.1 - 2	0.1 - 1
V	2 - 10	4 - 6	Ni	1 - 2	2 - 15
Pb	1 - 25	<1 - 6	Li	1 - 5	2 - 4
Zn	5 - 200				

TABLE 4

Short-circuit flow via well screens

$$Q = \frac{2\pi l^3}{r_o A} N(1 - \frac{\bar{z}}{D})$$

Q = short-circuit flow (l^3/t)

r_o = radius (l)

N = effective precipitation (l/t)

$2l$ = length of well screen (l)

$\bar{z}$ = main depth of well screen (l)

D = thickness of aquifer (l)

α = $1/r_o$

and for $l \gg r_o$

$A = 400 \ln(2\alpha) - 2\alpha \ln(4\alpha) - 2\alpha + 3$

Some calculations for $D = 40$ m and $N = 10^{-3}$ m/d

Length of screen m	$2r_o$ cm	depth of screen m - l.s.	Q m^3/y
10	5.7	0 - 10	2.6
10	5.7	20 - 30	1.1
10	2.5	0 - 10	2.2
2	5.7	8 - 10	0.14
2	5.7	23 - 25	0.07

TABLE 5

Basic analysis programme

KjN	Ca^{2+}	Zn	$KMnO_4$
NO_3^-	Mg^{2+}	Ni	TOC
Cl^-	Na^+	As	VOCl
SO_4^{2-}	K^+	pH	EOCl
HCO_3^-	tot. P	Eh	
	Conductivity		

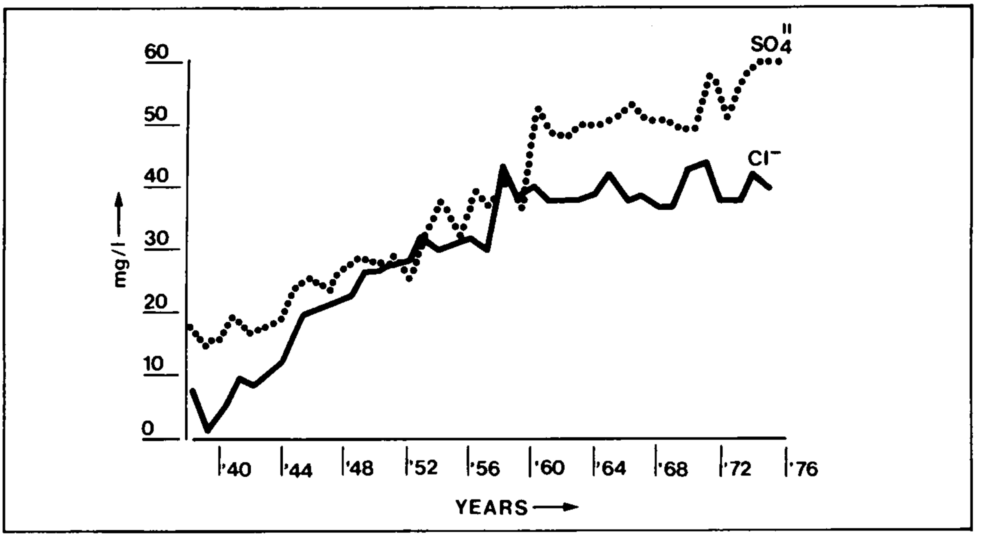
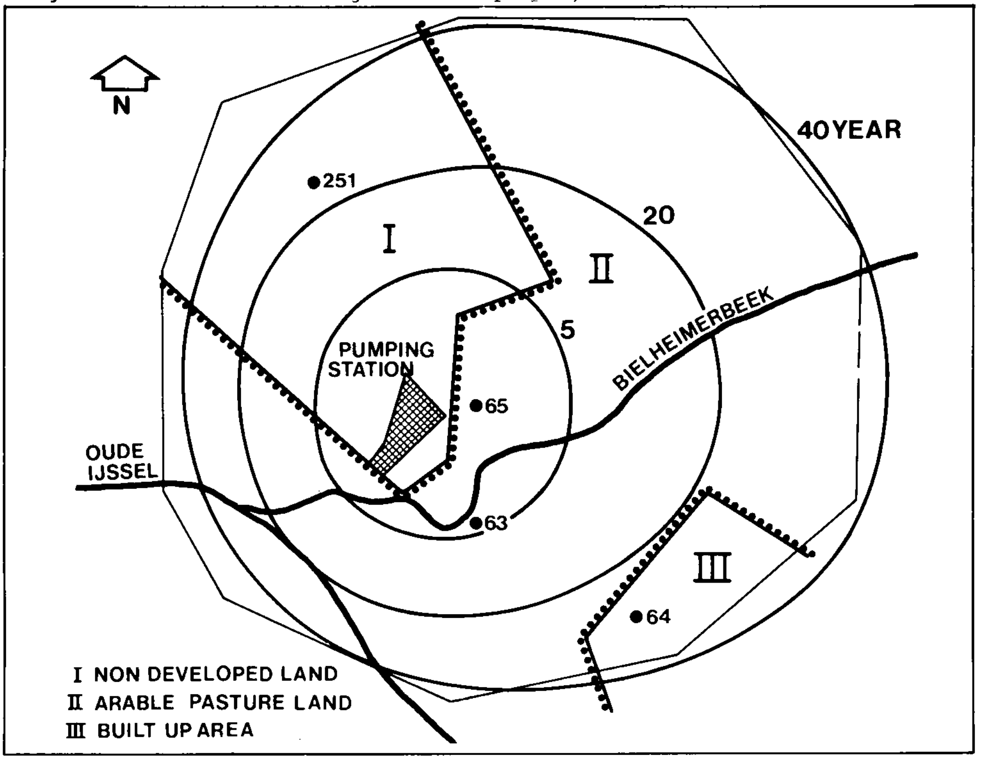


Figure 1. Trend of the quality of groundwater at pumping station 'De Pol'

Figure 2. Catchment area groundwater pumping station 'De Pol'



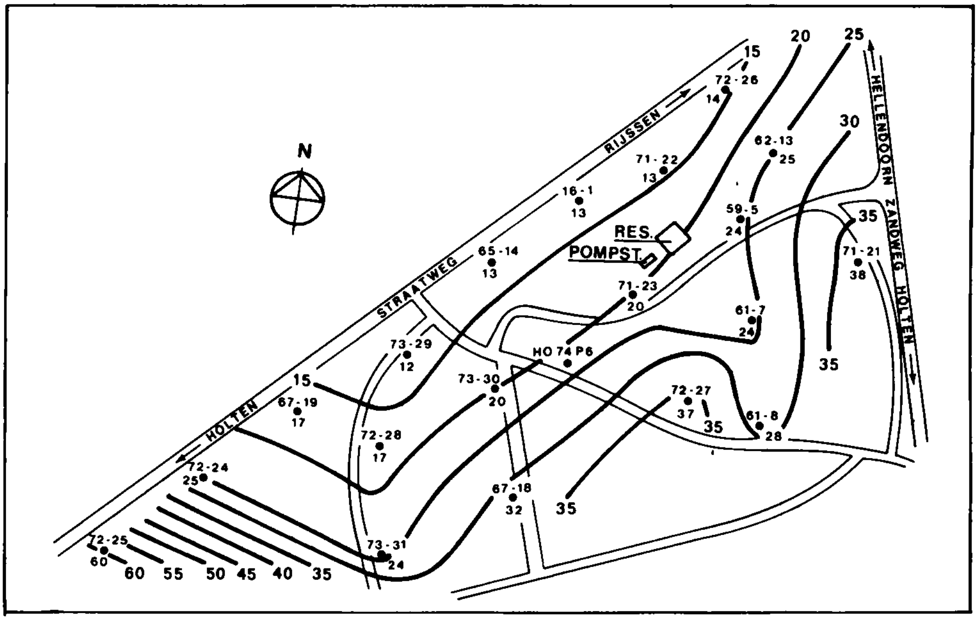


Figure 3a. Groundwaterpumping station Holten 25.09.1974
Isolines for Cl^- (mg/l)

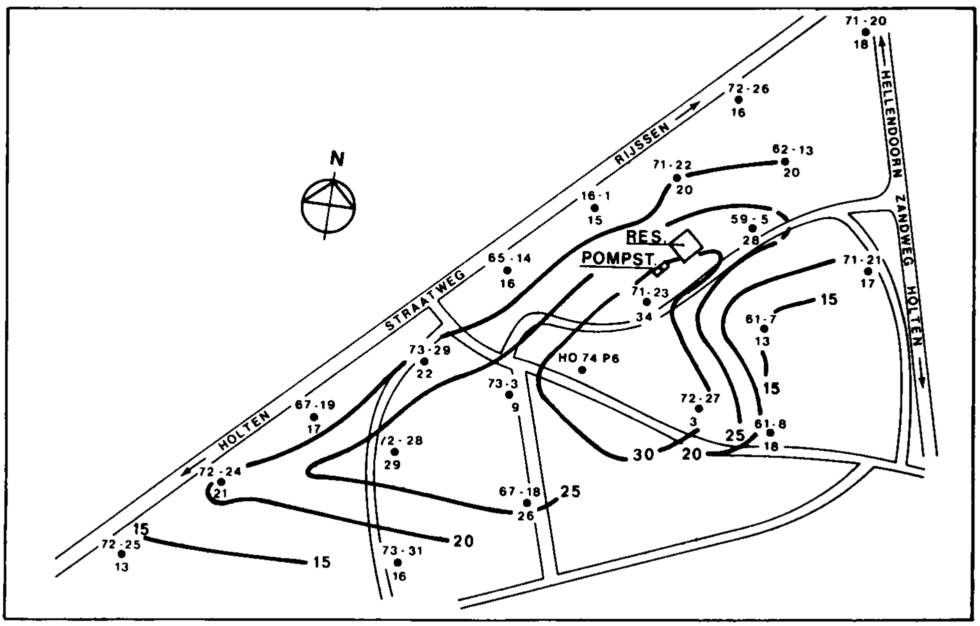


Figure 3b. Isolines for HCO_3^- (mg/l)

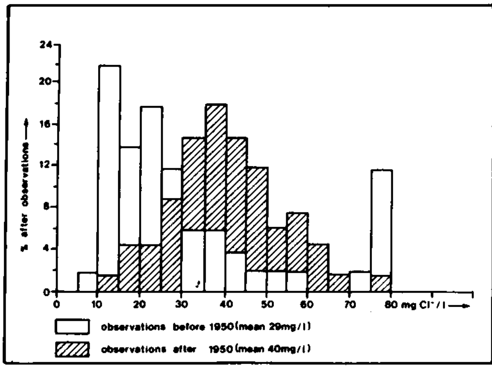


Figure 4a. Chloride contents in the sampled groundwaters in The Achterhoek between 10 and 22.5 meters below surface

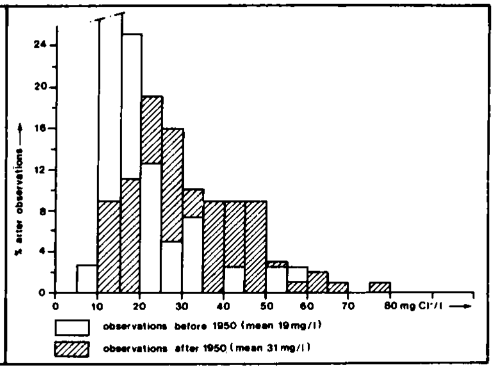


Figure 4b. Chloride contents in the sampled groundwaters in The Achterhoek between 22.5 and 40 meters below surface

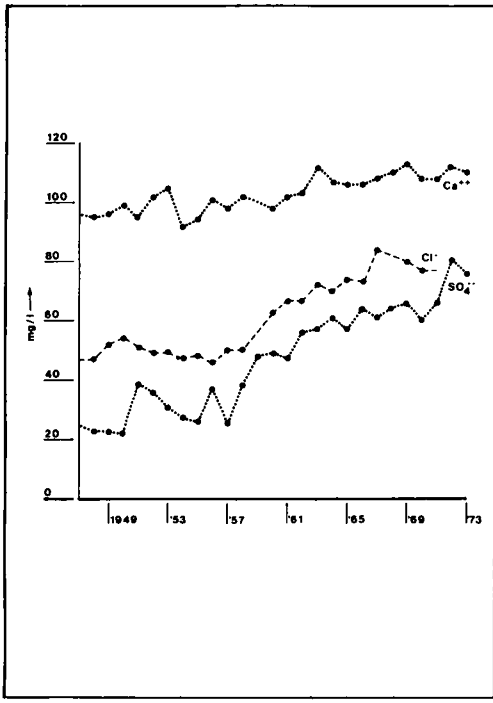


Figure 5. Effects of air pollution on groundwater quality

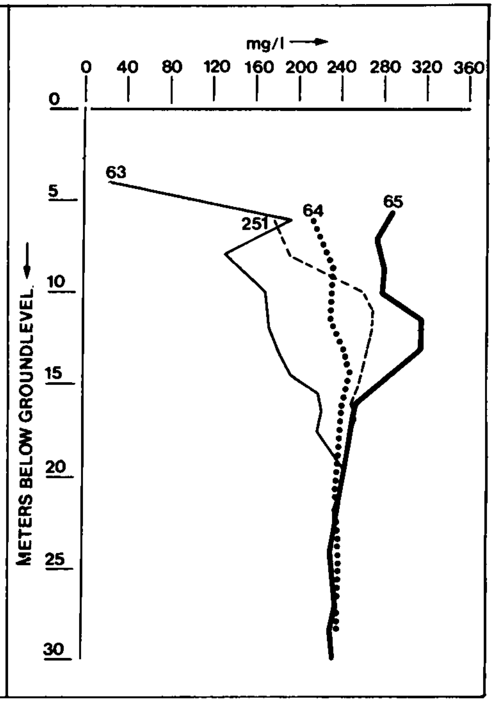


Figure 6. HCO_3^- content in groundwater over depth measured in y wells situated near to each other

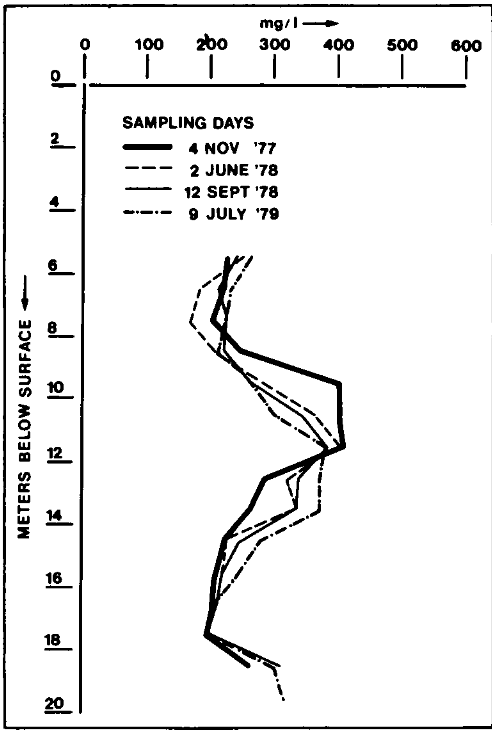


Figure 7. HCO_3^- content in groundwater in a dune area over depth and time (borehole 300-152)

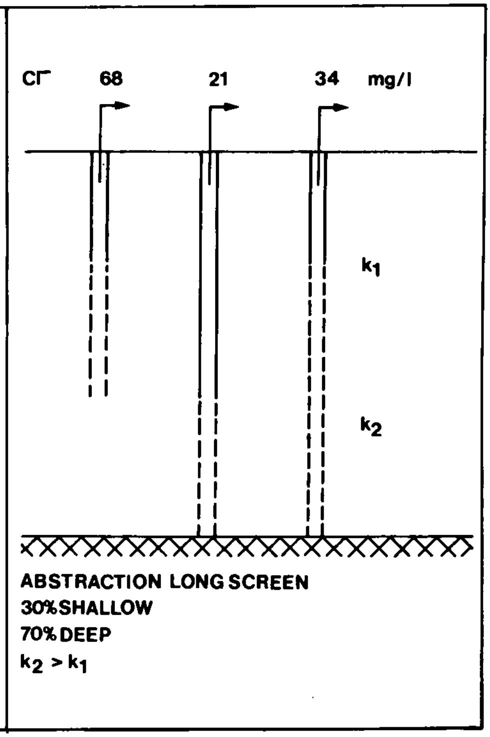


Figure 8. Research location Uddel

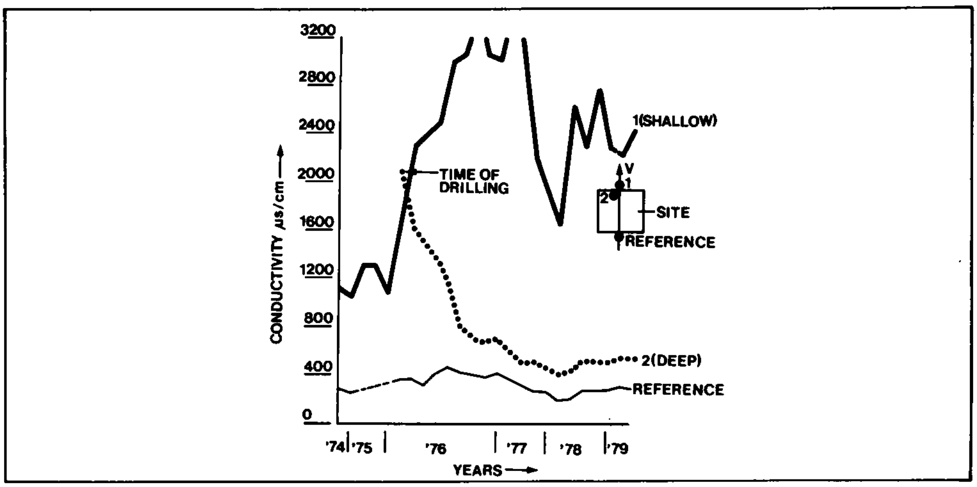


Figure 9. Trend of the quality of groundwater at a waste disposal site

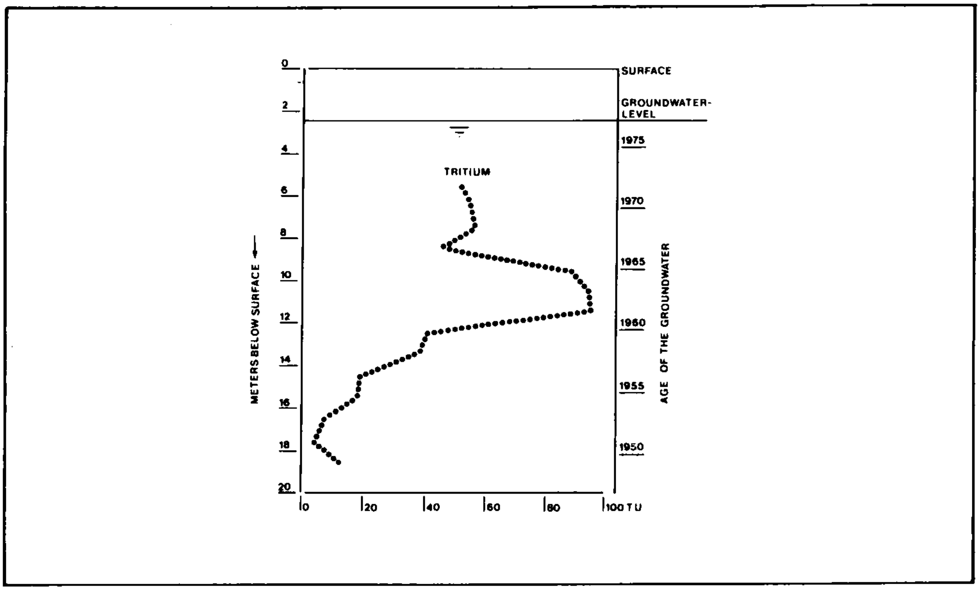


Figure 10. Determination of the age of groundwater by tritium measurements

Figure 11. Scheme monitoring station