

EFFECTS ON GROUNDWATER FLOW AND GROUNDWATER QUALITY OF A WASTE DISPOSAL SITE
IN NOORDWIJK, THE NETHERLANDS

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ABSTRACT

The effects of a waste disposal site in Noordwijk on the groundwater flow and groundwater quality were investigated. Special attention is given to the extension of pollutants in the aquifer. Several boreholes were made and groundwater has been sampled and analysed. Measurement of electrical resistivity and an electromagnetical investigation were carried out. Already beneath the landfill pollution was found on the fresh- salt water boundary at about 40 meters -l.s. A very large vertical flow component due to density flow could be calculated. Local flow patterns indicate an all-sided migration of pollutants. Short-circuit flow caused by the drilling of boreholes can effect the quality of groundwater seriously.

INTRODUCTION

The waste disposal site at Noordwijk is situated in a former sandpit near the dunes. The average depth of the sandpit is about 13 meters. In the central part of the sandpit the maximum depth is 16 - 17 meters. The groundwater level lies about one meter below surface. From 1960 to 1973 the sandpit has been used as a waste disposal site. The waste was deposited till about 3 meters above the former surface level. Some preliminary research was carried out during the period 1975 - 1976. Upon request of the Ministry of Public Health and Environmental Protection a more intensive research was started in 1977 concerning the influence of the waste disposal site on the groundwater flow and groundwater quality. For this research 22 monitoring wells have been drilled, from which five with a depth of 60 meters. One borehole was drilled through the central part of the waste disposal site. Normal and mini-screens were placed in the wells. Once or twice a year the groundwater around, below and inside the landfill was monitored. Groundwater samples were analysed on macro- and trace elements, on organic micro-pollutants and tritium. Moreover, electrical resistivity and electromagnetical measurements around the landfill were carried out and temperature measurements were made.

GEOHYDROLOGY

Based upon the information gathered during the research the geohydrological situation around the landfill can be described as follows: (see figure 1)

- 0 - 18 m -l.s. a medium permeable phreatic aquifer; clayey fine to medium coarse sand with loam and/or thin clay layers (Holocene);
- 18 - 57 m -l.s. permeable aquifer; coarse sand (Pleistocene);
- 57 - 105 m -l.s. impervious clay layers of the Formation of Kedichem (base of the aquifer).

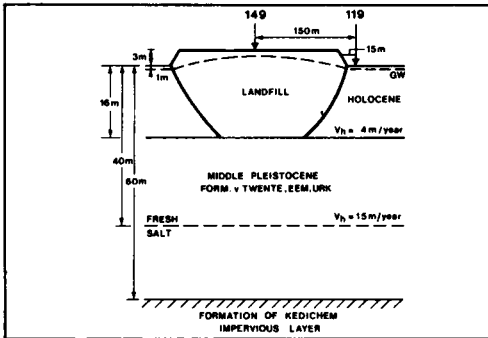


Figure 1. Cross-section of the landfill and hydrogeological situation

Below about 40 m -l.s. brackish groundwater is found. Generally the groundwater flow is directed towards the lower situated polderarea South-East of the landfill. On an average the velocity of the groundwater in the holocene aquifer is about 4 meters a year and in the pleistocene aquifer with a higher permeability about 10 - 15 meters per year. The area upstream and directly downstream the landfill is an infiltration area. Further downstream in the polderarea, there is an upwards seepage and therefore a raised fresh- salt water boundary. Locally the groundwater flow in the holocene aquifer is strongly influenced by the landfill, while the groundwater in the pleistocene aquifer is influenced by effects of density flow. In the following sections attention will be given to these phenomena.

DISPLACEMENT OF THE LEACHATE

During the excavation of the former sandpit a silty layer has been deposited. The resistance of this layer against waterflow probably causes the raised groundwater level inside the landfill (see figure 2). This raised groundwater level result in an all-sided migration of leachate into the aquifer. This prevents normal groundwater flow through the landfill. The outflowing leachate is replenished by precipitation infiltrating in the landfill. The extension of the pollution of the groundwater in the holocene aquifer can be illustrated by lines of equal resistance based upon electrical resistancy measurements around the site (see figure 3). In this survey contamination of groundwater was found in a zone between 4 and 12 meters

-1.s. till 30 meters upstream and about 80 meters downstream of the landfill. The results of the electromagnetical measurements are very similar. According to the results of analyses of water samples, only a slight influence of groundwater quality could be found in the deeper part of the aquifer. On the other hand the pollution plume on the fresh- and salt water boundary could not be detected by the electrical resistance measurements, due to the disturbing effect of the brackish water.

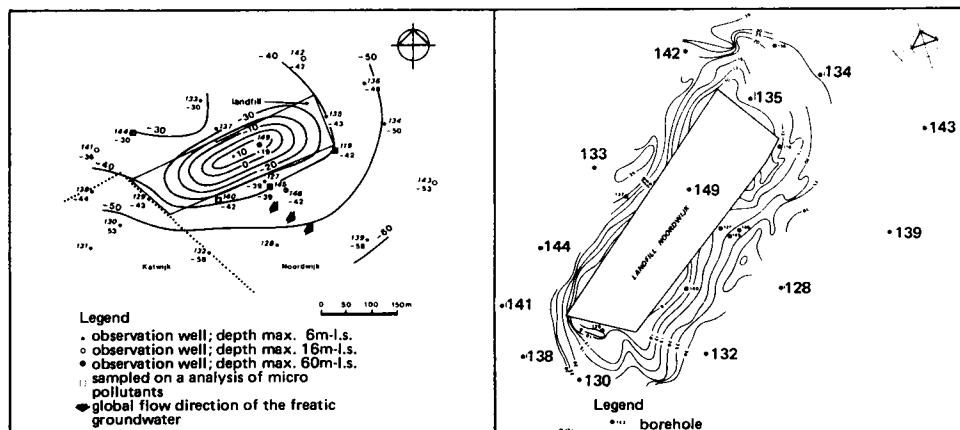


Figure 2. Equipotential lines of the phreatic groundwater

Figure 3. Aquiresistance lines around the landfill

To get more insight in the leachate migration in the pleistocene aquifer just beneath the landfill, a borehole through the waste disposal site was sunk (1978). In the borehole every 1½ meter a mini-screen was placed (in total 28). Likewise 13 electrodes and 9 normal, 2 meters long wells were placed. From these screens and electrodes 3 were placed in the landfill, divided by artificially made clay layers. During the drilling, leachate run down the borehole site, due to short-circuit flow. This resulted locally in a contamination of the groundwater in the pleistocene aquifer. It took nearly 1 year before the situation was stabilized as could be detected by measurements with the electrodes (see fig. 4).

The actual situation of the dispersion of the leachate in the environment is illustrated by figure 5, based upon the HCO_3^- concentration in the groundwater. Very similar figures are found for several other parameters (e.g. ^3H (tritium), Li^+ , Ba^{2+} , K^+ , NH_4^+). Except for some heavy metals adsorption seems to be not important in this coarse sanded aquifer.

Based upon figure 5, the following remarks can be made:

- In agreement with the conclusion that replenishment of outflowing leachate only takes place by precipitation, the total dissolved solids of the groundwater in the landfill increase with depth;
- According to the results of the electrical resistivity investigation the pollution of the groundwater near borehole 145 is comparatively less than near borehole 119, both at about the same distance from the landfill. Probably there is a lower flow

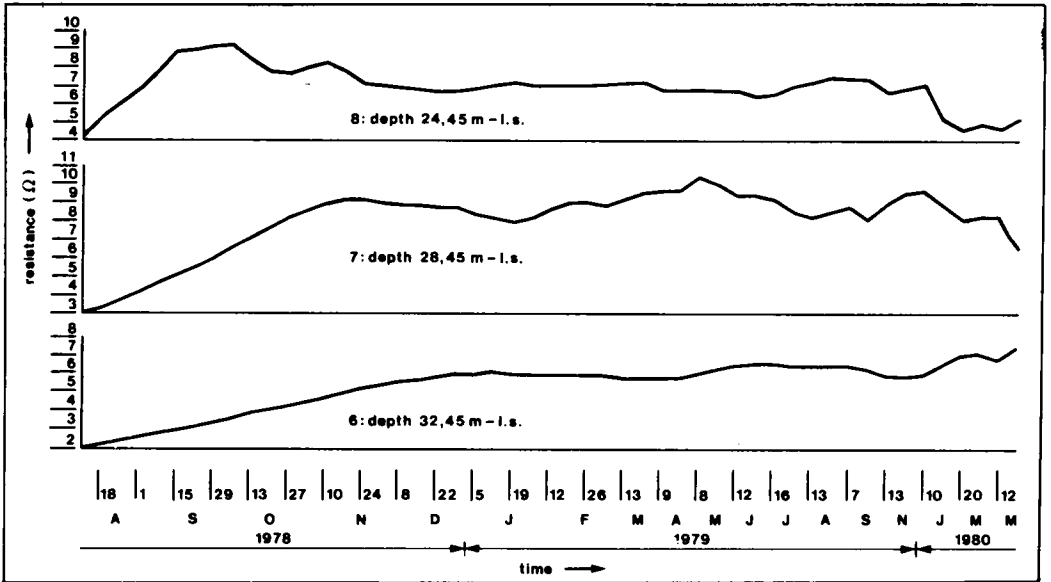


Figure 4. Resistance measurements beneath the landfill as a function of time

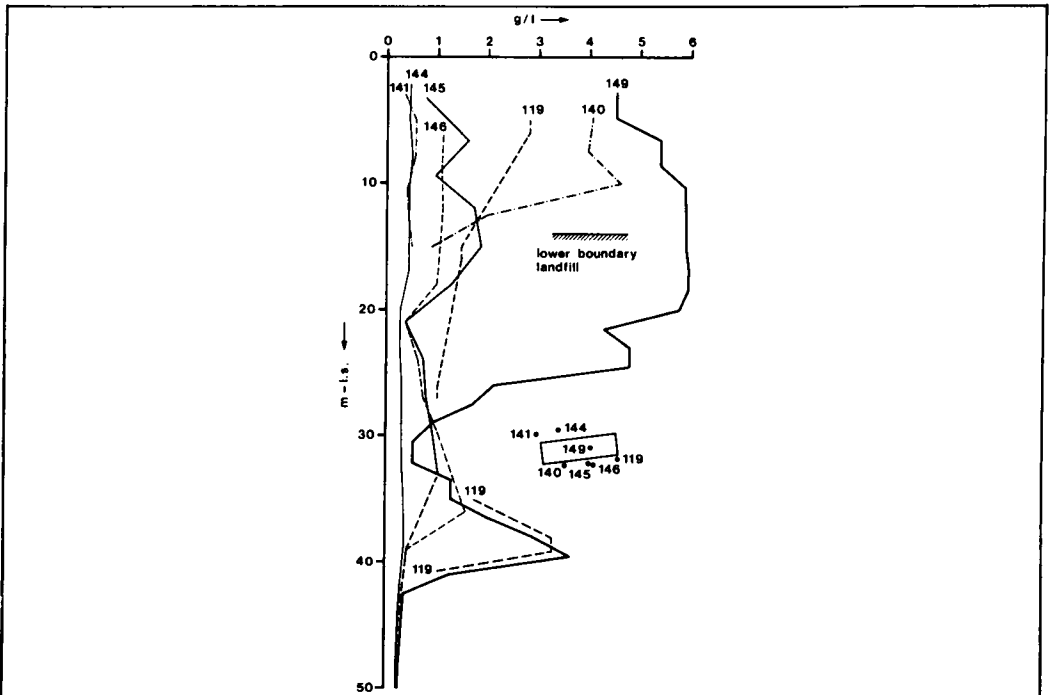


Figure 5. HCO_3^- concentration with depth date of sampling 18.07.1979

velocity of the groundwater near the central part of the landfill.

- From the bottom of the landfill till about 27 meters -l.s., the groundwater is heavily polluted with almost pure leachate. At the same depth the groundwater downstream the landfill is only slightly polluted.
- From 27 meters -l.s. to about 35 meters -l.s. a less contaminated zone is present in the groundwater beneath the landfill. While from 35 meters -l.s. to about 41 meters -l.s. just above the brackish groundwater a pollution plume appears with about half the concentration of the leachate. This is probably due to density flow combined with dispersion.

Especially the pollution plume at 35 - 41 meters -l.s. is very remarkable. An explanation of this phenomenon can be found in density flow. The density of the leachate is 1.0094 kg/l while the density of the polluted groundwater just above the salty groundwater and the non-polluted groundwater is respectively 1.0051 and 1.00027 kg/l. It is interesting to point out that the temperature profiles do not coincide with the chemical pollution profiles. This stresses the effect of density flow.

DENSITY FLOW

Density flow may take place by front displacement. However, in a natural situation 'fingering' of the heavier fluid into the lighter fluid will occur. Fingers will form if the mobility ratio is:

$$M = \frac{k_1 \mu_2}{k_2 \mu_1} > 1 \quad (k_1 \text{ and } k_2 \text{ are the variable transmissivities of the aquifer, } \mu_1$$

and μ_2 are the viscosities of the fluids).

A finger or drop of leachate will move down with an extra vertical flow component due to density and viscosity differences with the non-contaminated water. For a first estimation of the possible density effects in Noordwijk the models of Obdam (1979) and Kruijtzer (1980) are used.

The formula of Obdam can be described as follows:

$$v_{\rho z} = \frac{k_z}{\mu_q} (\rho_s g - \rho_q g) \frac{1}{n} \frac{\mu_q}{\mu_s}$$

- with:
- $v_{\rho z}$ = vertical flow component due to density differences
 - k_z = intrinsic vertical permeability
 - μ_s = viscosity of the leachate
 - μ_q = viscosity of the natural groundwater
 - ρ_s = density of the leachate
 - ρ_q = density of the normal groundwater
 - n = porosity
 - g = gravity

The formula of Kruijtzter is similar, but differs a factor 2/3 due to the finite dimensions of the displaced heavier fluid. With these formulas (with $k_z = 10$ meters per day, $n = 0.33$, ρ_s (average) = 1.0072 kg/l and $\rho_q = 1.0027$ kg/l) it can be calculated that $v_{pz} = 50 - 90$ meters per year for the situation in Noordwijk. This means that according to the analysis results already beneath the landfill pollution of the groundwater can be expected on the fresh- salt water transition zone.

QUALITY OF THE GROUNDWATER

In the above, attention is given to the extension of the pollution based on the conservative behaviour of the pollutants. In fact the behaviour of many macro parameters, even the positive ones, seems to be conservative due to the low adsorption capacity of the soil (<1 meq/100 gr) in the middle-deep aquifer. On the other hand, a clear preference adsorption takes place of several heavy metals. Some analysis results are given in table 1.

TABLE 1 QUALITY OF GROUNDWATER AND LEACHATE

Parameter	Leachate	Grw. 4 m be- neath base of landfill	Grw. 27 m be- neath base of landfill	Grw. 30 m be- neath base of landfill	Grw. bore- hole 119 38 m -l.s.	Ref. well 144 35 m -l.s.
Cl ⁻ mg/l	3310	3090	1200	2380	1670	44
SO ₄ ²⁻ "	37	92	9	52	28	4
HCO ₃ ⁻ "	5920	5510	1110	3090	3230	312
NH ₄ ⁺ "	700	640	114	72	236	1.4
Fe ⁺⁺ "	56	53	4.3	2.8	9.3	0.5
Ca ⁺⁺ "	280	278	109	252	340	27
Mg ⁺⁺ "	232	232	70	382	153	38
Na ⁺ "	2000	1850	680	1500	1100	42
K ⁺ "	880	820	170	145	475	22
Ba ⁺⁺ µg/l	900	900	100	500	700	50
Li "	500	485	105	110	270	5
Ni "	100	80	10	30	20	
Zn "	310	270	50	20	20	
benzene "	100	30	10		10	--
toluene "	300	100	3		3	1
xylene "	600	400	100		300	1
ethylbenzene	300	100	30		100	0.3
C ₉ H ₁₂ "	300	100	30		30	3
phenols "	200	90	20		90	--
camphor "	1000	100	100		100	--
org. chloor	26	14	4		16	--

Of special interest are the so-called organic micro-pollutants which are found in relatively high concentrations in the leachate. Further downstream there seems to be a clear reduction or degradation (see also Zoeteman et al., 1981) of these components.

Concerning the determination of heavy metals it can be pointed out that depending on the way of sample-handling, destruction and analysis of the heavily contaminated leachate and groundwater a wide concentration range can be found. For that reason an uniform approach seems to be very important.

Very interesting is the tritium concentration beneath and around the landfill. Besides the effects of the nuclear tests in the sixties (van Duijvenbooden, 1981), there is also an effect of the landfill itself. The tritium concentrations in the leachate clearly increased compared to the concentrations in the surrounding groundwaters of the same age. This holds true for the polluted as well as for the non-polluted groundwater (see table 2).

TABLE 2 TRITIUM CONTENT IN THE LEACHATE AND GROUNDWATER AROUND THE LANDFILL IN T.U.

depth m	reference wells		leachate	polluted groundwater	
	-1.s. well	well 141		well 140	well 145
7	109	88	143	112	93
10	42	7	133	116	103
15	8	12	158	63	88

CONCLUSIONS

Based upon the research results the following conclusions can be made:

- Density flow can be an important phenomenon near waste disposal sites. Looking at the possible high vertical flow component, it will be necessary, in case of monitoring, to sink observation wells to the base of the aquifer.
- When drilling a borehole through a polluted area, contamination of the aquifer can take place by short-circuit flow. Dependent on the local situation it can take considerable time before the original situation is restored. For this reason some delay time is necessary before sampling can take place.
- In case of a landfill situated in and above the groundwater, a water-divide can be formed in the landfill resulting in an all-sided migration of landfill leachate. This means that no groundwater is flowing through the landfill and also that the groundwater upstream can be contaminated. This demands a correct choice of reference wells.
- By measuring electrical resistivity or by electromagnetical investigation a passable insight can be obtained in the extension of the pollution in a horizontal as well as in a vertical sense. This reduces the necessary number of observation wells. On the other hand it must be kept in mind that in this way no information

can be obtained about the presence of pollution above a clay base or fresh-salt water transition zone due to the disturbing effects of this base or the brackish water.

- Electromagnetical investigation seems to give the same results as electrical resistivity measuring. The electromagnetical method works faster and is much cheaper than the electro resistivity one.
- Tritium seems to be a acceptable tracer to detect polluted groundwater descended from a waste disposal site.
- Temperature profiles in general do not coincide with profiles of the chemical parameters, probably due to density effects. This means that temperature measurements cannot be used for the tracing of chemical pollution.
- Depending on the way of sample-handling destruction and analysis, a wide concentration range can be found for many trace elements in the leachate and heavy polluted groundwater. This requires an uniform approach, for getting comparative concentrations.

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