Industrial waste disposal site Münchehagen: Confinement of dissolved contaminants by discharging saline water

by

K.U.Weyer, Ph.D., P.Geol.and D.A. van Everdingen, Ph.D.
WDA Consultants Inc.
Suite 310, 510- 5th Street S.W., Calgary, Alberta, Canada
Contact Email: weyer@wda-consultants.com

European office:

WKC Consultants
Eitelstr. 70,
40472 Düsseldorf, Germany

Solutions'95
International Association of Hydrogeologists Congress June 4-10, 1995
Edmonton, Alberta, Canada

Format-revised copy of Session "V", Paper 4 of the Proceedings
published in 1995 as a CD by MOW-TECH LTD.
Email: info@mowtech.com
Phone: 1-780-484-6356

Industrial waste disposal site Münchehagen: Confinement of dissolved contaminants by discharging saline water.

K.U.Weyer, Ph.D., P.Geol. and D.A. van Everdingen, Ph.D.
WDA Consultants Inc.,Suite 310, 510 - 5th St. S.W., Calgary, Alberta, Canada
European office: WKC Consultants, Eitelstr. 70, 40472 Düsseldorf, Germany

Abstract

Subsurface migration of contaminants is primarily a function of groundwater flow direction. The main constraints to groundwater flow are the configuration of the groundwater table and the distribution of variously permeable subsurface layers. In response to these parameters and thermodynamic constraints distinct local, intermediate, and regional groundwater flow systems co-exist.

Contamination in one flow system normally cannot migrate into another flow system. Thus groundwater dynamics are an efficient means to determine the direction and endpoint of contaminant migration and to predict which parts of the subsurface will remain untouched by a migrating contaminant.

The thermodynamic position and configuration of all parts of a groundwater flow system are integrally related. The regional, often saline, flow system, bounded by the groundwater surface, determines and contains the configuration of local groundwater flow systems.

The configuration of groundwater flow and contaminant migration at the Münchehagen (Germany) waste disposal site is an excellent example of how regional groundwater flow can, near regional discharge areas, restrict the migration of dissolved contaminants within a local groundwater flow system.

At Münchehagen regional discharge of saline water effectively confines the migration of dissolved contaminants to the limited volume of the local flow system. The regional flow system originates in the Rehburg Hills, some 7 km away, and penetrates 800-900 m into evaporitic layers before discharging saline water [spec. conductivity 55000 μS/cm; density = 1.026 g/cm^3] into the channel of the river Ils. In accordance with the hydrodynamic principles of potential theory an approximate solution of this variable density flow has been calculated with a cross-sectional mathematical model.

The model reflects to a remarkable degree the extensive hydrodynamic and hydrochemical measurements from the site. At Münchehagen, dissolved contaminant migration is confined to a limited part of the subsurface by the regional flow of saline water within the thermodynamic entity of the overall groundwater flow system.

Industrial waste disposal site Münchehagen: Confinement of dissolved contaminants by discharging saline water.

K.U.Weyer, Ph.D., P.Geol. and D.A. van Everdingen, Ph.D.
WDA Consultants Inc.,Suite 310, 510 - 5th St. S.W., Calgary, Alberta, Canada
European office: WKC Consultants, Eitelstr. 70, 40472 Düsseldorf, Germany

Introduction

In the subsurface, migration of contaminants is primarily a function of groundwater flow direction. Groundwater flow directions are controlled by the water table configuration, which in turn is highly dependent on topography, and by the spatial distribution of variously permeable layers through which the groundwater flows. The effect of these boundary conditions and parameters is the development of distinct regional and local flow systems.

This paper describes the control that regional and local flow systems exert over the migration of contaminants through the example of an industrial waste disposal site near Münchehagen in Germany taken from Weyer (1995).

The special industrial waste disposal site (SAD) at Münchehagen was deposited between 1968 and 1973, and between 1977 and 1983. Data were available only from the published literature in Canada and Germany, including geological maps of the states of Lower Saxony (Niedersachsen) and North-Rhine Westphalia (Nordrhein-Westfalen). The Münchehagen area lies in Lower Saxony close to the border of North-Rhine Westphalia.

This study was in part a test of whether readily available information would be useful during the planning stages of landfill sites to provide an initial judgment of the groundwater hydrodynamics in an area. This study will also show that saline waters with densities of 1.026 gm/cm^3 flow upward into overlying freshwater, in discharge areas of regional groundwater flow systems.

Münchehagen landfill site and surroundings

The relief in the Münchehagen area is relatively low (Figure 1: bird's eye view from the SE). The main hills in the area, the Rehburg Hills (Rehburger Berge), lie about 7 km to the north-east of the Münchehagen landfill. The

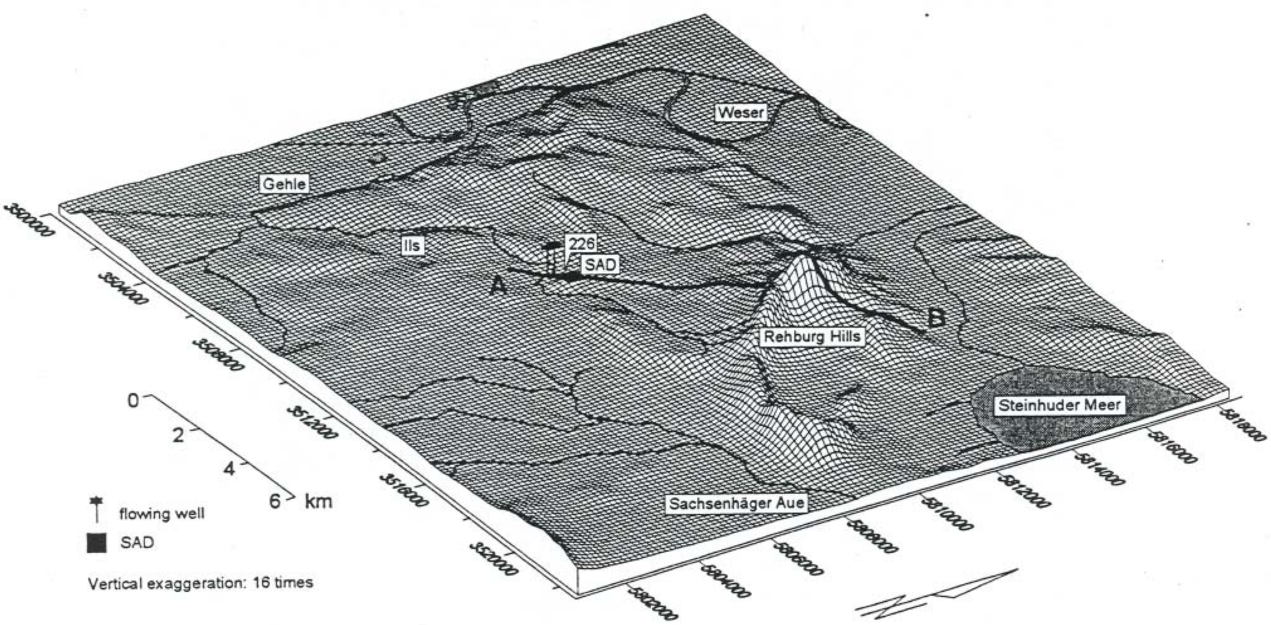

Fig. 1 Digital elevation model of area in the vicinity of the industrial landfill site Münchehagen [SAD] showing the location of flowing wells at the river Ils. A-B: Location of geological cross-section and mathematical model. Birds eye view from SE.

stream channel of the small river Ils lies about 300 m to the south-east of the landfill. The flat topography (note the 16 times vertical exaggeration on the digital elevation model of Figure 1) could suggest that the regional groundwater flow system does not play a role in the transport of contaminants. We suggest that the regional groundwater flow system does play a definitive role in that it locally confines the contaminants.

Dörhöfer and Kilger (1984) stated for the Münchehagen area that "Recent groundwater usually overlies a layer of old and almost motionless saline groundwater; this is confirmed by isotopic investigations (e.g. tritium)". However, the deep groundwater discharging into the Ils channel is saline. In the past it was thought that this was the result of saline water "coning" caused by water being extracted or sucked out of the ground either by the river or through pumping at the landfill site.

Figure 2, modified after Lüdeke (1987), suggests lateral flow directions for the fresh groundwater in the upper weathered clay layer. A mean permeability of $5x10^{-6}$m/s for the subsurface units was determined through a large number of pump, slug and packer tests; the effective porosity is 0.6-1.1% (Gronemeier et al., 1990). The groundwater table gradient is about 1:150; through tracer tests, a groundwater velocity of approximately 40 m/yr was determined (Dörhöfer and Fritz, 1988).

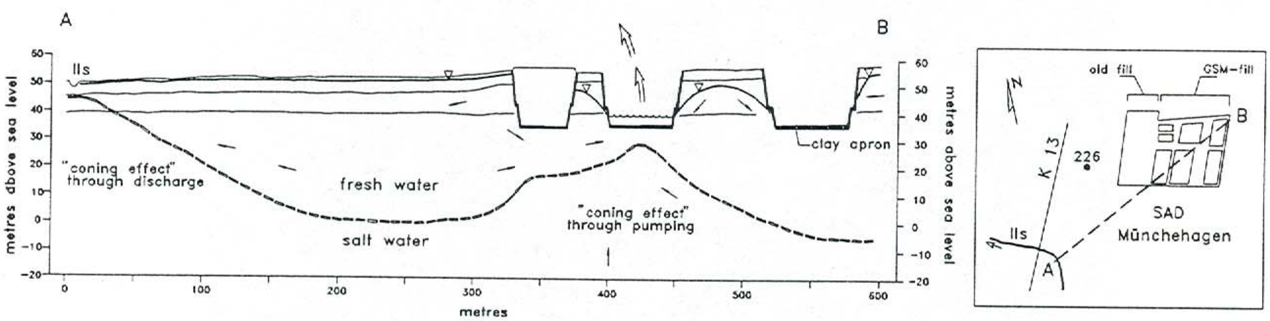

Fig. 2 Discharge of saline water at the river Ils (natural discharge) and at the Münchehagen landfill site (induced discharge). Insert shows the layout of the landfill. Modified after Lüdeke (1987, Fig. Page 242 and 243).

Gronemeier et al. (1990) indicated that the general direction of groundwater flow is from the Rehburg Hills in the north-east to the Weser river in the south-west. This is the direction of the cross-section and numerical model discussed in the following section (Figures 3 and 4). In all, about 100 piezometers were installed in the vicinity of the Münchehagen landfill (Dörhöfer, personal communication, 1992). Between July 1988 and April 1989 detailed hydrogeological investigations were carried out at Münchehagen by Gronemeier et al. (1990).

Originally the clay layers underlying the Münchehagen area were considered to be impermeable (Lüdeke, 1987, p.240). Dörhöfer and Kilger (1984) described the vertical permeabilities of the clay layers determined through slug tests. These permeabilities (10^{-7} to 10^{-5} m/s) indicated that the clays were not impermeable. The geology in the area consists of a claystone overlying marly claystone and sandstone. Beneath these layers are several units of marl and evaporites.

Numerical Model

The geological cross-section from the Rehburg Hills through the Münchehagen landfill was constructed using public topographic and geological maps (Jordan, 1979; Rohde, 1992) (Figure 3A; see line A-B in Figure 1 for location of section). Table 1 lists the relative permeabilities assigned by us to the various layers in the numerical model. No model calibration was performed.

Table 1: Geology and assigned relative permeabilities near Münchehagen

Formation Name	Abbr.	Geology	Permeability Eastern half Loccum	Permeability Western half Rehburg
Quarternary	Q	sand, cobbles	--	--
Cretaceous	Krv	claystone 5-15m	200	--
	"	15-50m	100	--
	"	deeper Krv layers	50	--
Wealdon 1, 2	WD 1+2	marly claystone	5	1
Wealdon 3, 4	WD 3+4	sandstone	10	100
Wealdon 5, 6	WD 5+6	layered claystone	1	1
Serpulit	joS	marly claystone	10	10
Mündener Mergel	joM	marl	100	100
Mündener Mergel	joM/Ev	marl with evaporites	100	100
Heersumer	joH-E	limestone, marl, anhydrite	100	100
mid-Jurassic	jm	clayey sandstone	10	10
low-Jurassic	ju	claystone	10	10

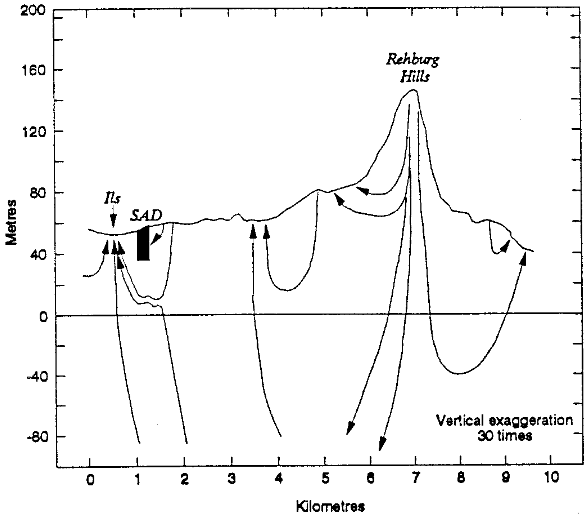

Fig.4 Cross-section A-B showing schematic flow lines and the local groundwater flow system in the vicinity of the Münchehagen landfill. Vertical exaggeration is 30:1.

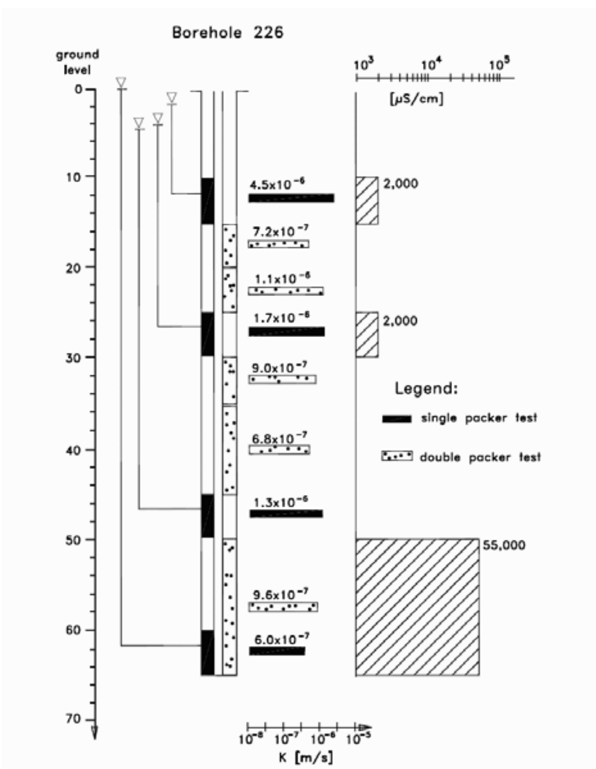

Fig. 5 Typical vertical head distribution and electrical conductivity near the Münchehagen landfill, Borehole 226 (Gronemeier et al., 1990, Fig. 7).

The model was run using a two dimensional vertical finite element grid (Figure 3B) in the FLONET program (Guiger et al., 1991). The results (Figure 3C) show that there is a regional flow system recharging in the Rehburg Hills and discharging at the Ils channel. Several local flow systems flowing south-westward are situated within the regional flow system. One of these, containing the Münchehagen landfill, recharges northeast and in the area of the landfill and discharges south-west of the landfill in a low area and into the Ils. At the Rehburg Hills the regional system flows downward to the marls and evaporites at 800-900 metres depth and then flows laterally to the south-west. The deep flow then moves upward beneath the landfill area where, on meeting the local flow system cell, it flows laterally and then up to the Ils channel. The schematic Figure 4 (vertical exaggeration of 30:1) shows how well developed the boundary is between the regional and local flow systems at the Münchehagen industrial waste disposal site. The occurrence of flowing wells (Gronemeier et al., 1990, p.287; for location see Figure 1 of this report) is consistent with the discharge of local and regional groundwater flow.

Interpretation

Groundwater flow follows force gradients in gravitational and pressure potential fields (Hubbert, 1940, 1957; Weyer, 1978). In the case considered, the regional groundwater system recharges precipitation in the area of the Rehburg Hills. There the subsurface is highly permeable as evidenced by past flooding in former coal mines (Jordan, 1979). The regional topography may be relatively flat but, as evidenced by the numerical model, is still enough to drive the flow of groundwater from the Rehburg Hills toward the Ils channel (and possibly further towards the Weser river). The river Ils does not pump nor does it suck water out of the ground. The flow into the river is driven by force fields caused by gravity.

The saline water has a higher density than the fresh water. Dörhöfer and Kilger (1984, p381) and Gronemeier et al. (1990, p282) consider the saline water to be 'formation water' thus implying it originated from the time of sedimentation and diagenesis. This is not the case; the saline groundwater at Münchehagen originates from precipitation which flows through salt-containing layers. The flow time is likely to be several thousands to tens of thousands of years, which explains why no recent tritium from atomic bombs could be found by Dörhöfer and Kilger (1984). There is no reason to name the saline water 'formation water'. Evaporite layers are the source of the salinity in the flowing groundwater.

The Ghyben-Herzberg relation describes the position of fresh water above saline water. This relationship, however, only holds under hydrostatic conditions. Under hydrodynamic conditions, it is the relationship between the gravitational force and the pressure potential force which results in the movement of the saline water upward. Pumping merely provides a lowered discharge level. The saline water system is also a part of the whole groundwater system between the Rehburg Hills and the Ils channel near Münchehagen. The saline water moves up beneath the Ils channel, because the Ils is a regional discharge area for groundwater originating

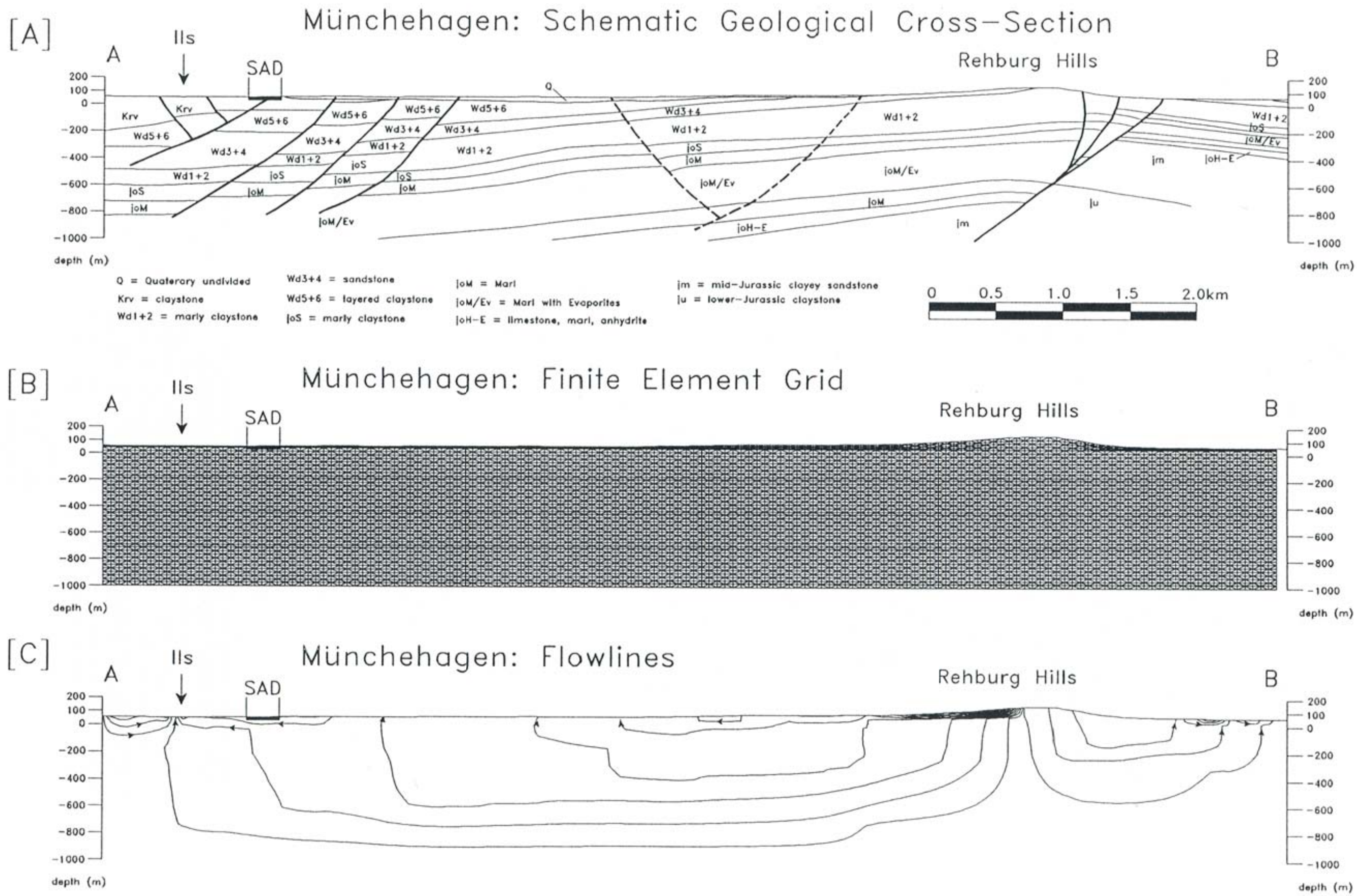

Fig. 3 A: Geological cross-section A-B (see Fig. 1). The geological profile was composed based on data from Jordan (1975) and Rohde (1992). B: Finite element grid for geological cross-section A-B. C: Vertical groundwater flow model Münchehagen: Flow lines in geological cross-section A-B. Vertical exaggeration is 1:1.

at the Rehburg Hills. The Ils is also the receiver of the local groundwater flow system in which the Münchehagen landfill lies. The saline water is not "almost motionless" (Dörhöfer and Kilger, 1984); it is part of the regional groundwater flow system. Therefore the hydrostatic conditions controlling the Ghyben-Herzberg relation do not apply.

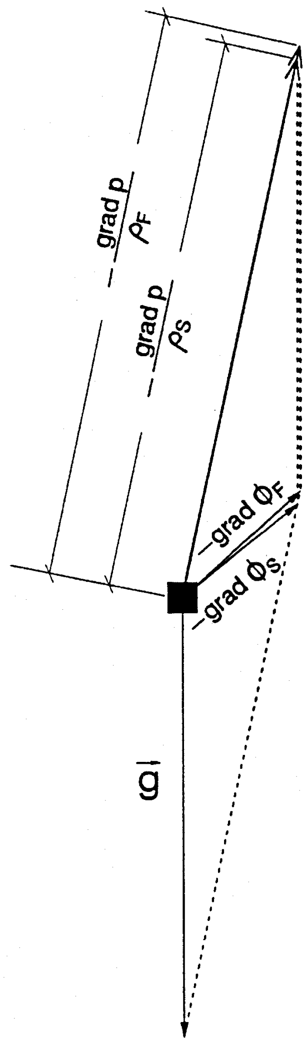

Fig. 6 Determination of forces affecting flow direction of freshwater (ρ_s=1.026 g/cm^3) in the discharge area of a hydraulic potential field. F=freshwater, S=saltwater. After Hubbert (1953, Fig. 16).

The deeper flow lines in the model (Figure 3C) are oriented horizontally within the Jurassic Münden Marl (Mündener Mergel: joM) from which the groundwater extracts the NaCl. One of the shown flow lines rises from the marl unit beneath the landfill; it then bends to the SW toward the river Ils. This is exactly what was determined in the field through the water level measurements by Gronemeier et al. (1990; Figure 5 in this report). It is now clear that the so called "coning effect" of Lüdeke (1987) and Dörhöfer and Kilger (1984) is the manifestation of upward directed gravitational flow of saline water in the regional discharge area along the river Ils.

Figure 5 shows the water levels at various depths in borehole 226. Borehole 226 is located near the Münchehagen landfill (Figure 2). The measured water levels clearly indicate that the borehole is situated in a local recharge zone with downward directed flow. At the same time, saline water flows up from below (see Figure 5: highest water level in the deepest measuring point in borehole 226). The local and regional flow systems encounter each other at a depth of approximately 50 metres in a somewhat higher permeability zone (K=1.3x10^{-6}m/s). In this zone, both waters flow laterally in the direction of the Ils channel. This has important consequences in that it suggests that the contaminant plume moves downward and then, upon meeting the upflowing saline water, moves laterally in the direction of the Ils channel, discharging in a low area.

The conductivity of the deep saline water in borehole 226 (Figure 5) is reported as 55,000 µS/cm, whereas measured conductivities in the upper part of the borehole are only 2000 µS/cm. Conversion of the high conductivity value, using tables from Rand et al. (1976; p.75 and p.105), give a density of 1.026 g/cm^3 for these saline waters, which are 2.6% denser than fresh water. Under hydrostatic conditions the denser fluid will sink beneath the lighter fluid. That the saline water discharges both beneath the river Ils and into the landfill, when pumped, indicates that the denser salt water can flow upward under hydrodynamic conditions. Application of potential theory explains the reasons for this behaviour.

The volume of a unit mass of saline water with a density of 1.026 g/cm^3 is 2.53% smaller than that of groundwater with a density of 1.0 g/cm^3. The increase in density results in a shortening of the pressure potential force per unit mass of water by 2.5%. The reduction of the pressure potential force by 2.5% produces only a small difference in the upward directed resultant flow direction (Figure 6). Therefore the saline water flows upward in discharge areas of hydrodynamic force fields.

Gronemeier et al. (1990) came to the following conclusions: The presence of benzene in high concentrations and its widespread occurrence in the rock is not explained at present together with the incomplete knowledge of the extent of the contaminant plume. Aromatic hydrocarbons are present in significant concentrations also outside the known area of the chlorinated hydrocarbons and in areas of the subsurface where Gronemeier et al. (1990, p.91) considered their occurrence as not concurrent with the known plume migration. We suggest that the new concept of local and regional groundwater flow in connection with vertical phase flow of chlorinated hydrocarbons may explain the differing occurrences of dissolved aromatic and chlorinated hydrocarbons.

It is of interest that circulation losses accompanied the drilling (Gronemeier et al., 1990, p.284); this is not commonly expected in claystone. The losses indicate the presence of fractures in the claystone which can become major pathways for the migration of contaminants.

Conclusions

In summary, it appears that the groundwater hydrodynamics at the Münchehagen landfill may not yet have been sufficiently investigated. We have the impression that the existing spatial distribution of the piezometers is not optimized for hydraulic purposes, and therefore also not optimized for hydrochemical purposes.

The Münchehagen landfill site, although one of the most studied in Germany, does not have enough piezometers installed suited to determine in detail the prevailing pattern of local and regional flow systems and the associated natural and contaminated hydrochemistry. Preliminary investigations of regional groundwater flow systems are inexpensive because they are based on available information (i.e. literature and maps). They are a necessary condition for the rational design of monitoring systems and remedial measures at waste disposal sites.

The hydrodynamic conditions, namely the upward flowing saline water in the regional flow system, prevents widespread migration of contaminants, because the Münchehagen landfill lies within a local flow system. Thus, at the Münchehagen landfill, the migration of contaminants could be effectively controlled by hydraulic methods.

References

Dörhöfer, G., and B. Kilger, 1984. Hydrogeological study of the suitability of lower Cretaceous claystone for the deposition of hazardous industrial wastes in Lower Saxony. In: Proceedings International Groundwater Symposium on Groundwater Resources, Utilization and Contaminant Hydrogeology. Montreal, Quebec, May 1984, vol.2, p.372-382, Canadian Chapter International Association of Hydrogeologists.

Dörhöfer, G., and J. Fritz, 1988. Geowissenschaftliche Untersuchungen zur Beurteilung des Sanierungserfordernisses von Altlasten am Beispiel der Sonderabfalldeponie Münchehagen, Niedersachsen [Geo-scientific investigations for the remediation of the Münchehagen industrial waste disposal site]. In: K.Wolf, W.J. van den Brink, and F.J. Colon. Altlastensanierung '88. Proceedings of Second International TNO/BMFT-Congress on Remediation of Waste Disposal Sites (Altlastensanierung), 11.-15. April, Hamburg. Vol.2, p. 1273-1276. Kluwer Academic Publishers, Dordrecht, Netherlands.

Gronemeier, K., H. Hammer, and J. Maier, 1990. Hydraulische und hydrodynamische Felduntersuchungen in klüftigen Sandsteinen für die geplante Sicherung einer Sonderabfalldeponie [Hydraulic and hydrodynamic field studies in fractured sandstone for the safe disposal of special industrial waste]. Zeitschr. dt.geol.Ges., vol.141 p.281-293, Hannover.

Guiger, N., J. Molson, E. Frind, and Th. Franz. 1991. FLONET version 1.02: Two dimensional steady-state flownet generator. Waterloo Centre for Groundwater Research, University of Waterloo, and Waterloo Hydrologic Software. Waterloo, Ontario, 57 p.

Hubbert, M.K., 1940. The theory of groundwater motion. J. Geol., USA, vol. 48(8), part 1, p.785-944.

Hubbert, M.K., 1953. Entrapment of petroleum under hydrodynamic conditions. Bulletin American Association Petroleum Geologists, vol.37(8) p.1954-2026.

Hubbert, M.K., 1957. Darcy's law and the field equation of the flow of underground fluids. Bulletin IASH, Nr. 5, p.24-59, Darcy Centennial Symposium, Dijon, France, September 1956.

Jordan, H., 1975. Geologische Karte von Niedersachsen 1:25,000, Sheet No. 3521 Rehburg, with explanations. 134 p., Hannover (contains contributions by H. Besenecker, E. Cosack, E. Dahms, H. Fauth, F. Gramann, B. Heinemann, E. Hofmeister, W. Kosmahl, J. Merkt, H. Schneekloth, J. Tüxen).

Lüdeke, H., 1987. Sicherungs- und Sanierungsmaßnahmen auf der Sonderabfalldeponie Münchehagen. [Safety and restoration preventative measures in the special waste landfill, Münchehagen]. Müll und Abfall, vol.19(6), p.240-248 (Figures page 242 and 243), Berlin, Bielefeld, München.

Rand, M.C., A.E. Greenberg, M.J. Taras, and M.A. Franson, 1976. Standard methods for the examination of water and wastewater. 14th edition. American Public Health Association, 1015-18th St N.W., Washington, D.C., 1193 p.

Rohde, P., 1992. Geologische Karte von Niedersachsen 1:25,000, Sheet No. 3520 Loccum, with explanations. 144

p., Hannover (contains contributions by A. Capelle, J. Fritz, W. Irrlitz, F. Kochel, M. Resch, P.-Ch. Scherler, K. Wilhelmi).

Weyer, K.U., 1978. Hydraulic forces in permeable media. Mémoires du B.R.G.M. [Bureau des Recherches Géologiques et Minière], vol. 91, p.285-297, Orléans, France.

Weyer, K.U., 1995. Darlegung und Anwendung der Dynamik von Grundwasserfließsystemen auf die Migration von gelösten Schadstoffen im Grundwasser. [Application of ground-water dynamics to the migration of dissolved contaminants] Consultants Report to German Environmental Protection Agency (Umweltbundesamt), Berlin, 2 vol., February 1995.