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Flow and transport modelling in old landfill subsoil with vertical barrier

La modélisation de flot et de transport d'eau au dessous de fondation de depôt ancienne avec de barriere contrfiltre verticale

E. Koda & E. Wiencław
Department of Geotechnical Engineering, Warsaw Agricultural University, Poland

ABSTRACT
Numerical modelling of groundwater flow and pollutant transport has been analyzed for an old sanitary landfill surrounded by a vertical bentonite barrier. The re-circulation system of leachate was also applied on the landfill. The FEMWATER numerical program was used for the modelling. The aim of the modelling was the assessment of the vertical barrier influence on shaping the groundwater level in the area, as well as determination of time infiltration of leachate in the waste body during recirculation. The results of groundwater monitoring were used to verify and tare the numerical model.

RÉSUMÉ
La modélisation numerique de flot et de transport de pollution a realisée pour le depôt ancienne entourée par le barriere protectrice verticale de parois contrfiltre dans le conditions de circulation de filtrat fermée. On a resoulus le problem a l'aide de program numerique FEMWATER. La modélisation a le but d'evaluer l'efficace de fonctionnement de barriere d'assurer l'eau souterraine á l'entourage de corps et pour déterminer le temps de deplacement de l'eau dans le corps de depôt. Pour la verification et le projet de modéle on utilise la recherche et l'observation par monitoring.

1 INTRODUCTION

Flow and transport modelling was performed for the Radiowo sanitary landfill located nearby Warsaw. This object exists since 1962, and permission for its exploitation is valid up to the end of the year 2005. Remedial works of this landfill have been conducted since 1994 and they include: vertical bentonite barrier, leachate drainage system, leachate recirculation system, technological roads and landfill shape, mineral cover, degassing system and also regulation of water relations in the area. Along the perimeter of the landfill, a one-phase cut-off wall barrier was constructed to minimize the spread of pollutants into the surrounding groundwater environment. The depth of the vertical barrier wall was 5-22m.

The control tests of the vertical bentonite barrier and subsoil were performed to determine the permeability parameters for the numerical model. Mainly, they should verify the continuity of a barrier wall, the demanded barrier depth related to natural aquitard layers as well as the sufficient low permeability and durability of the bentonite material. The hydraulic conductivity of the bentonite material in the laboratory was evaluated in a triaxial cell of variable hydraulic gradients, whereas a BAT system was used for determining this parameter in the field. Durability tests of the barrier wall involve hydraulic conductivity parameters estimated in long-term conditions, as well as water quality monitoring investigations in the surrounding area.

The local monitoring program includes chemical analyses of the leachate, surface and groundwater, as well as groundwater level observations. The results of groundwater monitoring were used to verify and tare the numerical model. The influence of the vertical barrier on the groundwater flow was also analyzed

2 SITE DESCRIPTION

The Radiowo landfill is located in the NW part of Warsaw. It started to operate in 1962 and no protection system was installed there at that time. Mixed municipal solid wastes were disposed there up to 1991. Since 1992 only non-composted wastes, i.e.: glass, plastics, textiles and scrap, have been stored there. It covers the area of approximately 16 ha and is almost 60 m high. Since 1998, remedial works have been carried out on the landfill. They include, among others: forming and planting of the slopes, stability reinforcement solution (lateral reinforcements and berms), mineral capping, bentonite cut-off wall and peripheral leachate drainage protecting groundwater pollution as well as leachate recirculation and degassing systems. It is expected that the landfill will be closed down in 2005. The local monitoring program includes chemical analyses of the leachate, surface and groundwater as well as G.W.L. observations.

The landfill subsoil consists of sandy soils, 2-5 m thick, locally to the depth of 20 m. In the upper part they are represented by dense sands, in the deeper part – by well-graded sands (from dense to coarse). This layer forms the first groundwater level with the groundwater table at the depth of 0-2 m below surface level. Water is supplied to this layer mainly by infiltration of precipitation and water inflow from the forest area located in the south-east. Dewatering trenches from the NE and W part, as well as a stream (from the N), compose a local drainage system for the first groundwater level. Leachates from the landfill and rain water from the compostory area are pumped to the landfill surface (recirculation system).

The vertical bentonite barrier surrounding the landfill was constructed within 1999-2001. The 0.6-m wide barrier was performed at the depth of 2 m below the top of clayey soils, i.e. 3.5-22.0 m below surface level. This aquitard layer consists of boulder and Tertiary clays.

3 THE MODEL OF GROUNDWATER FLOW AND TRANSPORT

The numerical model of groundwater flow was prepared with the use of GMS/FEMWATER software (GMS 2000; Lin et al., 2000). The basis of the FEMWATER flow model is the 3-D solution of the task of groundwater flow and transport. Numerical modelling was focused on the assessment of the vertical barrier influence on hydrogeological conditions in Radiowo landfill area and determination of time infiltration of leachate in the waste body during recirculation.

The governing Richards' partial differential equation, is used in FEMWATER program to describe groundwater flow:

$$\nabla\left[k_r k_s \left(\nabla h + \nabla z\right)\right] + q = F\frac{\partial h}{\partial t} \tag{1}$$

$$F = \frac{d\theta}{dt} \tag{2}$$

where: k_r = relative hydraulic conductivity; k_s = saturated hydraulic conductivity tensor; H = pressure head; q = source/sink discharge; t = time; F = differential water capacity; θ = volume moisture content.

Generally, it can be assumed that: F, θ and k_r are functions depending on h. In the model, these relations were defined as functions described by van Genuchten (1980).

The governing equations used in the FEMWATER model for transport are worked out based on the continuity of mass and flux laws. The major processes are advection, dispersion, diffusion, adsorption and decay. In the presented model, the transport process was respected as the advective migration of a single dissolved indicator (Cl^-). It can be described by the equation:

$$\theta\frac{\partial C}{\partial t} + V\nabla C = 0 \tag{3}$$

where: θ = volume moisture content; V = discharge velocity vector (Darcy flux); C = material concentration in aqueous phase; t = time.

Fig. 1 presents the generated model mesh, whereas the assigned boundary conditions for the flow and transport modelling are shown in Fig. 2. The analyzed technical solution for the model simulation consists of the protection system including the vertical barrier to stop leachate outflow from the landfill and applying of leachate re-circulation. The model mesh consists of 8903 elements and 5289 nodes. The total area covered by the model is approximately 88 ha, including 16 ha of the landfill area (Koda & Wiencław, 2005).

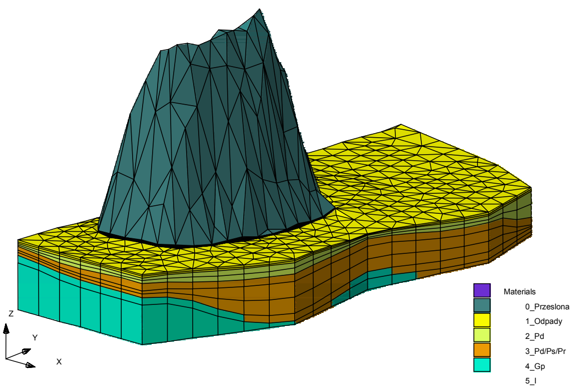

Figure 1. The 3-D GMS numerical mesh for the Radiowo landfill.

In the numerical model, taking into account the deposits within the subsoil and the hydrogeological conditions in the landfill surroundings (Koda, 1999), four landfill subsoil materials have been distinguished. Municipal wastes are placed in the model center, as well as in the upper part. Along the landfill border there is the vertical bentonite barrier (cut-off wall) with hydraulic conductivity of $k_s=5\times10^{-10}$m/s (Koda & Skutnik, 2003). Volumes of moisture content of wastes were tested by Koda & Zakowicz (1998), whereas for other selected materials are assumed after Carsel & Parrish (1988). The values of the hydraulic conductivity coefficient k_s in the saturation zone, volume water capacity θ(h) and relative hydraulic conductivity k_r(h) for soils in the landfill subsoil, wastes and bentonite material, assumed in the numerical model, are shown in Table 1.

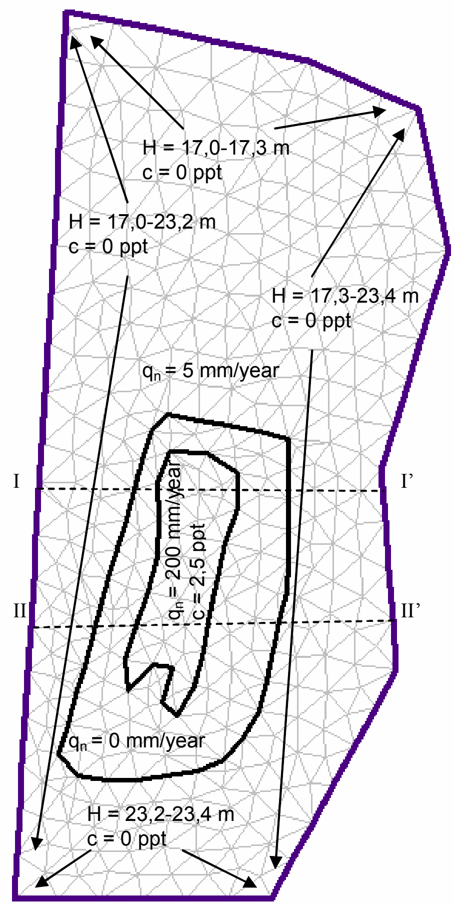

Figure 2. Boundary conditions for the flow and transport numerical model of the Radiowo landfill surroundings.

Table 1: Soils/material parameters for numerical model

Material	k_s [m/s]	θ [cm^3/cm^3]	k_r [-]
Bentonite	5×10^{-10}	0.36	0.99-1.0
Wastes	1×10^{-4}	0.055-0.43	0.37-1.0
Dense sand	5×10^{-5}	0.43	0.99-1.0
Non-uniform graded sands	1×10^{-4}	0.43	0.99-1.0
Sandy clays	1×10^{-7}	0.38	1.0
Tertiary clays	5×10^{-9}	0.35	1.0

On the location map, the model outside the borders is overlapped with surface streams in the landfill surroundings. These streams were shaped in the numerical model as assigned in Dirichlet's boundary conditions. The constant hydraulic gradient equals to the water table level in these streams, reaching from 17 (in the northern part of area) to 23.45 m above "0" level (in the southern part of area), while for pollutant transport C=0.

Neuman's boundary conditions (q_N=200 mm/year with Cl^- concentration of C=2.5 p.p.t. (ca. 2500 $mgCl^-/dm^3$) were assigned in the model for the part of the landfill area (ca. 0.44 ha), where the leachate and rainwater from the compostory plant are pumped (re-circulation). In the case of intensive precipitation, Neuman's boundary condition was also taken into consideration in the model, i.e. on the high inclination slopes of q_N=0, whereas in the surroundings it was assumed as q_N=0.005 mm/year (where C=0). The maximum level of the model reaches z=78 m, while the minimum vertical level only z=5 m.

The assumed initial conditions are shown on the contour map of G.W.L. for the situation from 1998 (Fig. 3), i.e. before construction of the vertical barrier and introduction of the leachate re-circulation. Initial condition for transport was C=0.

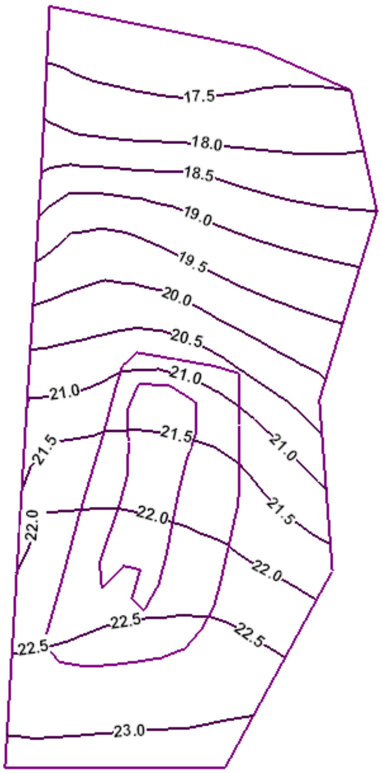

Figure 3. Initial hydraulic conditions (contour map of GWL in 1998, before remedial works starting).

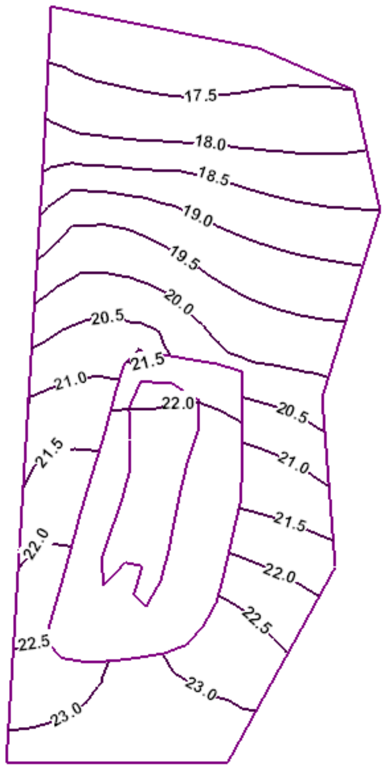

Figure 4. Groundwater contour map for the landfill subsoil with vertical barrier and leachate re-circulation system – 4 years after its exploitation.

4 MODELLING RESULTS OF FLOW AND TRANSPORT

The results of the numerical simulation of groundwater flow were worked out as a groundwater contour map (Fig. 4). The shape of the groundwater level and its oscillations, presented on the map, are suitable for stable flow conditions. For the design of landfill remediation, it was calculated that the groundwater level stabilization would be reached in 4 years.

Comparison of the two situations, before remedial works in the landfill (Fig. 3) and four years after construction of the vertical bentonite barrier, shows that the shape of the groundwater level in landfill surroundings has completely changed (Fig. 5).

Due to the vertical barrier construction and introduction of re-circulation of polluted water on the landfill surface, the groundwater (leachate) table level in the landfill area has also changed. On the landfill, the leachate level will decrease approximately by 0.30 m in the southern part, whilst in the central and northern parts of the landfill, the leachate level will increase by more than 1 m.

In the surrounding area, the groundwater level may increase or decrease, depending on the zone. The largest decrease of groundwater level (ca. 0.5 m) will take place in the northern part, in direct vicinity of the vertical barrier. However, the greatest increase of groundwater level (ca. 0.3 m) will occur in the part close to the southern part of the landfill. The vertical barrier composes the obstacle for S-N groundwater flow. The flow modelling results correspond with monitoring measurements (Golimowski & Koda, 2001).

Results of numerical simulation of leachate advective transport in the waste body and landfill subsoil are presented in cross-sections I-I' and II-II' in the form of leachate migration izochrons (Figs. 6 and 7). Referring to the purpose of modelling simulation, it is assumed that the leachate will reach the groundwater level in the landfill subsoil in ca. 40 years.

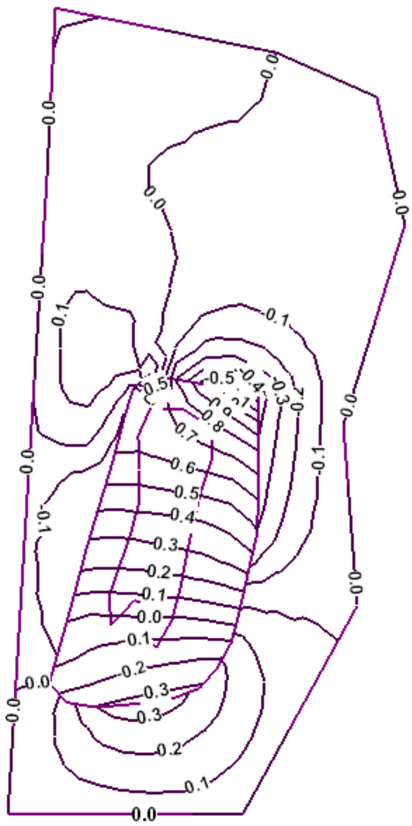

Figure 5. Contour map of changes of the groundwater level on the landfill and surroundings caused by vertical barrier and leachate re-circulation system.

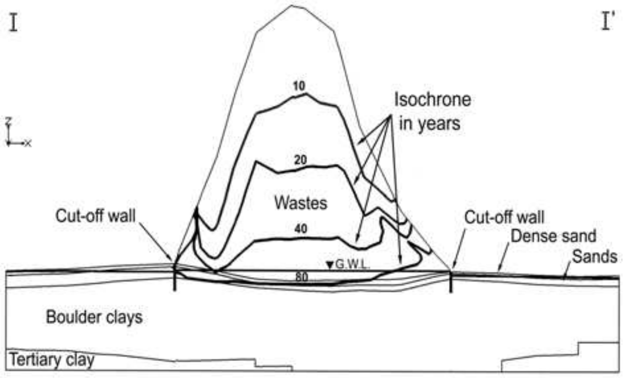

Figure 6. Isochrones from the numerical simulation of leachate advective transport in the waste body and the landfill subsoil in the cross-section I-I'.

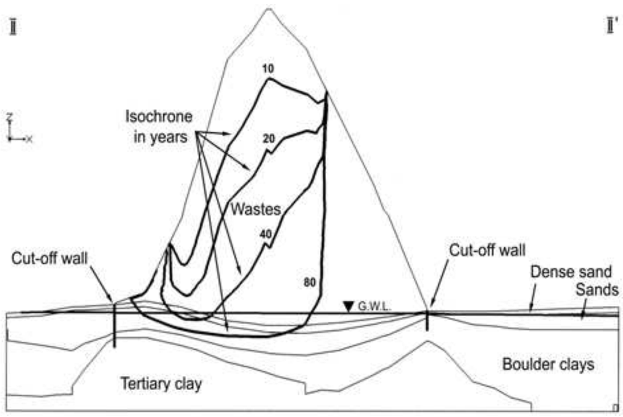

Figure 7. Isochrones from the numerical simulation of leachate advective transport in the waste body and the landfill subsoil in the cross-section II-II'.

5 SUMMARY AND CONCLUSIONS

The protection of groundwater against leachate from the Radiowo landfill is effected by system consisting of a cut-off wall barrier and peripheral drainage, additionally completed by a leachate recirculation system.

Numerical modelling is useful for quality assessment of the vertical barrier influence on the groundwater flow. The results of numerical modelling for the Radiowo landfill, presented and analyzed in the paper, proved the isolation role of the vertical bentonite barrier.

Due to the vertical bentonite barrier, construction and introduction of the recirculation system of polluted water on the landfill surface, the groundwater (leachate) table level in the landfill area (surrounded by vertical barrier) has also changed, i.e. decrease or increase in the leachate level appered, depending on the landfill zone.

Groundwater flow modelling results correspond to monitoring measurements in shallow piezometers installed in the surrounding area.

Referring to the purpose of transport modelling simulation in the Radiowo landfill, it is assumed that the leachate will reach the groundwater level in the landfill subsoil in 40 years.

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