Assessment of efficiency of the old landfill protection system based on transport modelling and monitoring research

Évaluation de l'efficacité du système de la protection du depôt ancienne a la base de recherche modellant de transport et monitoring

E. Koda
Warsaw University of Life Sciences, Poland, E-mail: eugeniusz_koda@sggw.pl

J. Golimowski
University of Warsaw, Faculty of Chemistry, Poland, E-mail: golim@chem.uw.edu.pl

E. Wiencław
Warsaw University of Life Sciences, Poland, E-mail: edward_wienclaw@sggw.pl

ABSTRACT
The paper describes the results of numerical modelling of pollution transport and groundwater quality monitoring for the old sanitary landfill where the advanced protection systems have been introduced. The protection system consists of the vertical bentonite barrier and peripheral leachate drainage. The FEMWATER numerical program has been used for groundwater flow and transport modelling. The control tests of the vertical barrier material and subsoil were performed to determine permeability parameters for the numerical model. The local monitoring program includes chemical analyses of leachates, surface and groundwater quality as well as groundwater level observations. The results of groundwater monitoring have been used for verification and tare of numerical model. The influence of remedial works on the groundwater quality on landfill surroundings has also been analysed in the paper.

RÉSUMÉ
L'article présente les résultats de model numérique de transport de pollution et de monitoring de la qualité d'eau souterraine dans la region du depôt, où on a utilisé le system de protection complete. Ils se composent de parois bentonite et de drainage leachate. Le programme numérique FEMWATER on a utilisé pour modelisation d'ecoulement et de transport. Les essais des materiaux de parois et fondation sont executés pour determiner les parametres de filtration du modele. Le programme de minitoring locale contient les analyses chimiques de composition d'écoulement, la qualité des eaux de surface et souterraine, ainsi que les mésures de la nappe phreatique. Les resultats on a utilisé pour tarage et verification du modele numerique. Dans l'article on a analysé ausi l'influence des travaux de recultivation sur la qualité des eaux souterraine dans la region du depôt.

Keywords : sanitary landfill, cut-off wall, transport modelling, water quality monitoring

1 INTRODUCTION

Sanitary landfill is a specific bioreactor in which wastes are decomposed under influence of aerobic and anaerobic conditions and microorganisms in chemical, physical and biological processes (Gryffin, 1991). Rainwater penetrates the wastes and dissolves products in the above-described biochemical processes and forms leachates. The chemical composition and physical properties of leachates originating from the sanitary landfill depend on: kind of stored wastes, climatic conditions, age of the landfill, the way in which wastes are disposed of and the landfill exploitation (Golimowski & Koda, 2001). Migration of the pollutants depends on geological conditions, which can be favorable to the transport of water and the substances it carries or it can completely stop and keep the transport away from the landfill.

In Poland there is still a large number of sanitary landfills where environmental protection standards are not fulfilled. Therefore, on these areas, the remedial works aimed at protecting the environment against progressive degradation should be carried out immediately. The example of engineering solutions of groundwater protection (cut-off bentonite barrier and peripheral drainage) applied for remediation of large embankment sanitary landfill in Radiowo is presented in the paper. In the case of the analyzed landfill, the basic remedial problem is connected with protection against leachate migration and groundwater pollution. In the future, it is envisaged that the Radiowo landfill will be adapted for recreation purposes (bicycle lanes, ski-lift, view points, etc.).

The assessment of remedial works efficiency was performed with the use of numerical transport modeling and analysis of groundwater quality monitoring in the landfill surroundings. FEMWATER numerical program has been used to solve the flow and transport problem. The control tests of the vertical barrier material and subsoil were performed to determine permeability parameters for the numerical model (Koda & Skutnik, 2003). The results of the groundwater monitoring were used for verification of the numerical model (Wiencław & Koda, 2004). It is observed that, after closing of the vertical barrier and construction of leachate drainage, the pollution concentration has been directed towards the groundwater flow.

2 REMEDIAL WORKS ON OLD LANDFILL TO ELIMINATE POLLUTION THREATS

The remedial works on the old landfills consist of technical and biological solutions aimed at eliminating the threats and propagating the areas for other purposes. The basic remedial works are aimed at elimination of groundwater degradation process and protection of surroundings against pollution (Koda, 1999). The main activities protecting environment against pollutions coming from old landfills are as follows:

- Waste body shaping with slope stability assurance;
- Leachate drainage and utilization systems;
- Groundwater protection system (cut-off barrier);
- Degassing system;
- Complex cover system and coat plant creation.

The schemes of the old landfill before and after remedial works are presented in Figure 1.

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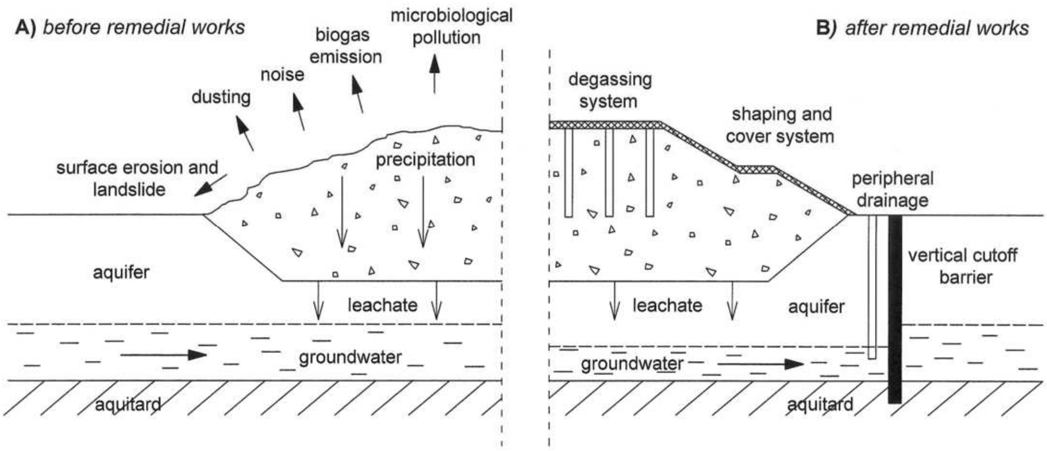

Figure 1. The old landfills schemes before and after remedial works performance.

3 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 other things: shaping and planting of the slopes, stability reinforcement solution (lateral reinforcements and berms), mineral capping, cut-off barrier 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 2009.

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 SE. Dewatering trenches from the NE and W parts, as well as a stream (from the N), compose a local drainage system for the first groundwater layer. 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 1999-2000. The 0.6 m wide bentonite barrier was established 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. Closure of the bentonite barrier contributed to significant improvement in the quality of the first groundwater layer and surface water in ditches. Large improvement in the surface water quality is visible at the first sight – small amounts of samples of groundwater water are colourless (in the past it was a brownish stinking liquid).

4 GROUNDWATER FLOW AND TRANSPORT MODEL

The numerical model of groundwater flow was constructed with the use of GMS/FEMWATER software (EMRL, 2005; Lin et al. 2000). The basis of the 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 the Radiowo landfill area.

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

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

where k_r is the relative hydraulic conductivity, k_s is the saturated hydraulic conductivity tensor, H is the pressure head, q is the source/sink discharge, t is time, $F=\partial\theta/\partial h$ is the differential water capacity and θ is the 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. In the presented model, the transport process was respected as the advective-dispersive migration of a single dissolved indicator (Cl^-). It can be described by the equations:

$$\theta\frac{\partial C}{\partial t} + V\cdot\nabla C - \nabla\cdot\left(\theta D\cdot\nabla C\right) = 0 \tag{2}$$

$$\theta D = a_T\left|V\right|\delta + \left(a_L - a_T\right)\frac{VV}{\left|V\right|} \tag{3}$$

where V is the discharge velocity vector (Darcy flux), C is the material concentration in aqueous phase, t is time, D is the dispersion coefficient, α_T is the transversal dispersivity, α_L is the longitudinal dispersivity and δ is Kroneckers delta.

The analyzed technical solution for the model simulation consists of the protection system including the vertical barrier to stop leachate outflow from the landfill. The total area covered by the model is approximately 88 ha, including 16 ha of the landfill area (Koda & Wiencław, 2005).

5 WATER QUALITY MONITORING

Analysis of water quality in the landfill neighbourhood is conducted according to local monitoring system which includes:

- 17 piezometers used to control the first groundwater layer,
- 1 deep well used to control the second water-bearing layer,
- 6 sampling points situated at surface watercourses (ditches),
- 4 sampling points of raw leachates (from leachater reservoirs).
- 1 sampling point of rainwater from the compostory area.

This network of points enables the appropriate control and estimation of the water quality in the vicinity of the landfill and compostory plant. Chemical analysis for underground water has been conducted since 1997. The analysis of water quality results reveals that introduction of the vertical barrier has positively changed the basic parameters of the first groundwater layer (Koda, 2004). This paper presents only basic parameters to characterize water quality. Detailed results of the monitoring research and its analysis are presented in annual reports. discussion of numerical modelling and water monitoring results

The technical works conducted according to reclamation project, including the introduced in 2000 vertical bentonite barrier (it was closed in 30.11.2000) and drainage system to separate leachates from the landfill helped to obtain significant improvement in the quality of groundwater and surface water in the vicinity of the landfill. Table 1 shows the influence of the above-mentioned reclamation operations, especially the influence of vertical bentonite barrier on the quality of groundwater in the aquifer layer during the years 2000-2007. The obtained results show that construction of the vertical barrier (see Table 1) significantly improved the water quality. The presented results have been obtained based on piezometer No 7A, where the vertical barrier was closed.

The numerical modelings of pollutant migration in the first groundwater layer as a map of chlorides concentration before the closure of the vertical barrier is shown in Figure 2, while the situation after 5 years later, is presented in Figure 3.

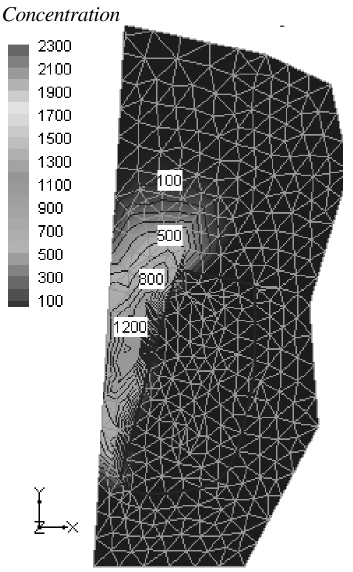

Figure 2. Chlorides concentration (mg Cl/dm^3) at the first groundwater layer before the vertical barrier construction acc. to numerical modeling.

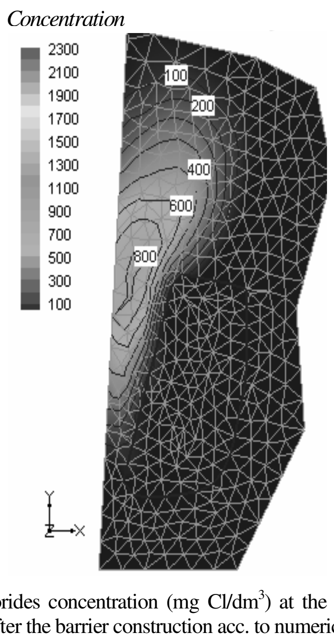

Figure 3. Chlorides concentration (mg Cl/dm^3) at the first groundwater layer 5 years after the barrier construction acc. to numerical modeling.

In Figure 3 the movement of pollution-slick towards groundwater flow direction is observed. Maximum chlorides concentration in the slick has been reduced significantly as a result of dilution. It is predicted that the chlorides concentration will be reduced by 2-3 times during the next 15 years, while total elimination of pollutions will take place in ca 30 years.

Verification of modeling results has been done based on water monitoring in the landfill surroundings. The Figures 4 and 5 present spatial distribution of chlorides concentration for two periods, i.e. before and 5 years after the closure of the vertical bentonite barrier.

Comparing the maps of chlorides distribution received from numerical modeling and monitoring, one can observe the analogy in the way of slick movement, confinement of polluted zone and decrease in maximum value of chlorides concentration. Pollution movements can significantly affect water quality in outflow direction. After 5 years from the vertical barrier closure, the maximum concentration was moved from the zone of piezometer No 7A to the zone of piezometer No 11A (Figure 6).

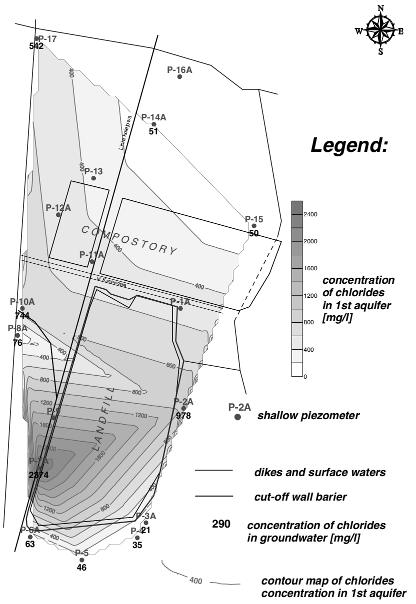

Figure 4. Chlorides concentration (mg Cl/dm^3) at the first groundwater layer before the vertical barrier construction acc. to monitoring results.

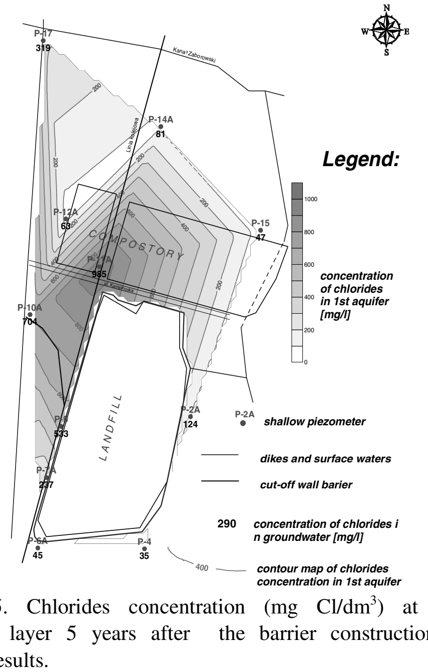

Figure 5. Chlorides concentration (mg Cl/dm^3) at the first groundwater layer 5 years after the barrier construction acc. to monitoring results.

Table 1. The influence of the vertical bentonite barrier surrounding landfill on groundwater quality in piezometer No P-7A

Pollution indicator	Unit	Date / Concentration of pollutants					
		11.07.2000	Closure of the vertical barrier, November 2000	20.06.2001	28.05.2003	7.11.2005	27.11.2007
Electrolytic conductivity	μS/cm	10830		8370	2800	3170	1509
BOD_5	mgO_2/dm^3	650		75	45	49	8,31
COD_{Cr}	mgO_2/dm^3	1758		226	159	193	109
Ammonium nitrogen	mgN_{NH4}/dm^3	97,7		14,1	1,8	0,29	0,04
Chlorides	$mgCl^-/dm^3$	2374		1595	340	274	79,5
Sulphates	$mgSO_4^{2-}/dm^3$	690		630	500	805	309
Copper	$mgCu/dm^3$	2,1		0,6	0,261	0,228	<0,002
Lead	$mgPb/dm^3$	0,2		0,05	0,005	0,004	<0,004

Figure 6 shows changes of chlorides concentrations for piezometers No. 7A and 11A. In piezometer No. 7A, situated close to the place where vertical barrier was finished, a significant decrease of pollutants can be observed (Table 1). The most significant reduction of pollutions concentration was noted for: electrolytic conductivity, BOD_5, COD_{Cr}, ammonium nitrogen and chlorides. Presently, all pollution indicators are lower than standard values for the third quality class of groundwater.

In piezometer No 11A, situated on groundwater outflow direction, the maximum values of pollutant concentration was reached 5 years after the closure of vertical barrier. From the last 3 years, decrease of pollutant concentration is observed also in piezometer No. 11A (Figure 6).

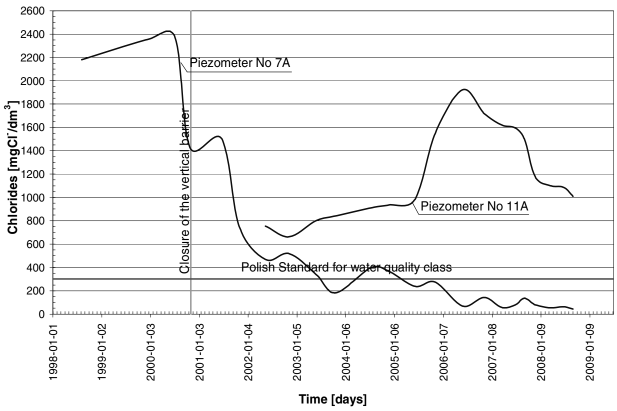

Figure 6. Moving of the maximum chlorides concentration (in mg Cl/dm^3) towards flow in the first groundwater layer from piezometer No 7A to piezometer No 11A.

6 SUMMARY AND CONCLUSIONS

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

The remedial works carried out on the Radiowo landfill proceed in the right direction and should be brought to the end soon. After closing of the vertical barrier, the quality of groundwater (first layer) has improved. Simultaneously, after closing of the vertical barrier the main pollution concentration has been moving towards groundwater flow direction.

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

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

Further reclamation attempts should mainly concentrate on: finishing the shape forming of the landfill and biological reclamation of its slopes, construction of the degassing system with farther utility of biogas and the introduction of effective purification procedures for leachates coming from the landfill drainage system.

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REFERENCES

EMRL 6.0. 2005. *Groundwater Modelling System – tutorial volume I-IV*, Birgham Young University, Provo UT.

Golimowski, J. & Koda, E. 2001. Assessment of remedial works effectiveness on water quality in the vicinity of landfill based on monitoring research. *Annals of Warsaw Agricultural University – SGGW, Land Reclamation*, No. 32: 17-30.

Gryffin A. 1991: *Principles of hazardous material management*. Plewia Publishers, London.

Koda, E. 1999. Remediation of old embankment sanitary landfills. *Proceedings of the 3rd BGE Conference on Geoenvironmental Engineering*, London: 29-38. London: Thomas Telford.

Koda E. 2004. Local water quality monitoring on surroundings of the sanitary landfill. *Annals of Warsaw Agricultural University – SGGW, Land Reclamation*, No. 35a: 131-144.

Koda E. & Skutnik Z. 2003. Quality control tests of vertical bentonite barriers for old sanitary landfill containment. *Proceedings of the 13th European Conference on Soil Mechanics and Geotechnical Engineering.*, Praha, Vol. 1: 409-414.

Koda, E. & Wiencław, E. 2005. Flow and transport modelling In old landfill subsoil with vertical barrier. *Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering.*, Osaka, Vol. 2: 921-924.

Lin, H.C.J., Richards, D.R., Yen, G.T., Cheng, J.R., Cheng, H.P. & Jones, N. 2000. FEMWATER – *A Three-Dimensional Finite Element Computer Model for Simulating Density-Dependent Flow and Transport in Variably Saturated Media. Technical Report CHL.* U.S. Army Engineer Waterways Experiment Station. Vicksburg.

Van Genuchten, M.T. 1980. A closed-form equation for predicting the hydraulic conductivity of saturated soils. *Soil Science Society Journal*, No. 44: 892-898.

Wiencław E., & Koda E. 2004. Groundwater flow modeling for old landfill with vertical barrier. *Annals of Warsaw Agricultural University – SGGW, Land Reclamation*, No. 35a: 229-336.