# Paper presented in ModelCare Conf. 2005

# Influence of Continuous Pumping on Detection of Contaminant Plumes Under Conditions of Uncertainty

**N. B. YEN¡GÜL, A. M. M. ELFEKI, &C. VAN DEN AKKER**

*Delft University of Technology, Faculty of Civil Engineering and Geosciences, Water Resources, P.O. Box 5048 2600GA Delft, The Netherlands*

e-mail: n.b.yenigul@citg.tudelft.nl

**Abstract** The focus of groundwater investigation has traditionally been on quantification of this resource, but increasing detections of contaminants during the last decades have shifted this focus towards assessment and protection of groundwater quality. Landfills are one of the major contamination sources that influence the groundwater quality. Therefore detection and characterization of the contaminant are crucial prerequisites of a monitoring network at a landfill sites. However the efficiency of such a network highly depends on the uncertainties due to subsurface heterogeneity and the nature of the landfill itself. The particular intention of this study is to investigate whether continuous pumping from the monitoring wells will improve the efficiency of the widely applied common practice that fulfils the minimum regulatory requirement, namely a monitoring network system of three downgradient wells. A hypothetical problem is presented where Monte Carlo framework is used to incorporate uncertainties due to subsurface heterogeneity and the leak location. Hydraulic conductivity and leak location are considered as random variables with prescribed probability density functions. A finite difference groundwater model coupled with a random walk particle-tracking model simulates a contaminant plume released from the landfill for each Monte Carlo realization. The efficiency the three well monitoring network has been compared for monitoring with and without pumping from the monitoring wells. It has been observed that the efficiency of monitoring network increases considerably by pumping from the monitoring wells. Furthermore, the analyses show that the pumping rate has a great influence on detection probability. The detection probability increases as the pumping rate increases.

**Keywords** uncertainty; monitoring; pumping; detection

## INTRODUCTION AND BACKGROUND INFORMATION

Contaminants are introduced in groundwater by planned human activities rather than by the natural phenomena. Landfills represent a widespread and significant threat to groundwater quality, human health and even some of the ecosystems due to their nature of operation and abundance.

Despite of the countermeasures and legislations the environmental impact of the landfill leakage, particularly on groundwater quality has been encountered quite frequently. Works by Chen and Wang (1997), Mato (1998), Heron et al. (1998), Mikac et al (1998) and, Riediker et al. (2000) are some of the examples have been presented in the literature. However, risk of groundwater contamination can be further reduced by monitoring groundwater quality via a network composed of a series of wells located around the landfill and sampled periodically for contaminants. Although it is often difficult to ensure that such a specific network will detect all of the contaminants released from the landfill due to the numerous significant uncertainties. Size and location of the possible contaminant leak, spatial variability of the hydrogeological characteristics; locations, depth and number of monitoring wells; chemical characteristics of contaminants and sampling frequency are the uncertainties that have great influence on detection probability of contaminant plumes.

Current most widely recognized and applied regulations (USEPA, 1986 and ECC, 1999) require installation of sufficient monitoring wells that can detect a contaminant leak before it crosses the compliance boundary. Minimum requirements are three downgradient wells and one upgradient well. The post closure monitoring time mentioned is 30 years, whereas the position, number (more than the minimum requirement) and depth of the monitoring wells are proposed by the landfill owners or operators and by local authorities. In current monitoring method sampling is carried out quarterly, biannually or annually depending on the type of waste, size and design of landfill and aquifer material. There is no recognition of the uncertainty in this requirement contrary to the reality.

The approaches based on geostatistical methods, optimization methods and methods based on extensive simulation are mostly used for groundwater quality monitoring networks design. Rouhani and Hall (1988) and Haugh et al. (1989) used geostatistical tools efficiently in their studies and considered hydrogeologic variability. However, since both models do not include flow or transport model they fall short of providing a systematic and consistent approach to design groundwater monitoring systems. Morisawa and Inonue (1991) used multiattribute utility theory in order to develop a network design method incorporating uncertainty and multiple objectives, including minimizing cost, maximizing the probability of detection and minimizing the expected time to detect a contaminant leak. Hudak and Loaiciga (1993) presented a multi-objective method that can be used to locate wells to provide the detection of contamination, but they did not consider uncertainty in their approach. Meyer et al. (1994), used a multiobjective stochastic optimization approach to determine the 2D location of monitoring wells. Storck et al. (1997) extended this model to three dimensions incorporating local dispersion. In both studies uncertainties due to subsurface heterogeneity and leak location are incorporated however the huge computational effort required for the extensive simulations is the main drawback. On the other hand Hudak (2002) devised a graphical approach to configure detection wells at the downgradient of a landfill but he did not consider the uncertainties due to the subsurface heterogeneity and contaminant leak location. Yenigul et. al. (2004) used a simulation model to analyse the reliability of groundwater monitoring systems at landfill sites by examining thoroughly the influence of several parameters that play an important role in monitoring network design, and to formulate a practical strategy.

The common point that has been observed in the previous studies is: mostly more than 3-wells to reach a satisfactory level of detection probability. In current monitoring method before taking a sample to monitor the groundwater quality water level of each monitoring well is purged by removing four well volumes of water using a bailer or a pump. Therefore the capture zone of a monitoring well is quite limited to detect a large number of the contaminant plumes released from a landfill. Especially when the medium is relatively low dispersive, the plumes initiated from point sources such as holes, tears, and imperfections in the liner systems will be narrow and difficult to detect unless the monitoring wells are located very close to each other. Therefore a large number of wells are required to achieve a satisfactory high performance level. However, this might not be so practical since the monitoring cost will be quite high. On the other hand, broadening the capture zone of monitoring wells will increase the chance of intercepting more contaminant plumes. Hence this study mainly investigates whether continuous pumping from the monitoring wells will improve the efficiency of the widely applied common practice that fulfils the minimum regulatory requirement (a monitoring network system of three downgradient wells) especially in low dispersive medium.

## PROCEDURE AND MODEL DESCRIPTION

A simulation-based model (adapted from Elfeki, 1996) coupled with a two-dimensional finite difference flow model and a random walk particle-tracking model is used to perform the numerical experiments. A Monte Carlo approach is used to generate a large number of equally likely contaminant plumes resulting from the failure of the lined landfill. Hydraulic conductivity field and leak location are the random inputs of the simulation model.

The natural logarithm of hydraulic conductivity [Y=ln (K)] is generated based on a Gaussian stationary distribution with a given mean, variance, and a correlation length. A local failure in the liner (impervious layer of clay or geotextile) is assumed to occur at a random location along the downgradient edge of the landfill. The detection of a contaminant plume occurs, if the concentration value at a given monitoring well exceeds the threshold concentration value. The monitoring network detects a plume when one of the monitoring well in the networks detects. Thus, the detection probability of a monitoring network, $P_d$, is estimated as the ratio of the number of simulation runs in which the contaminants are detected over the total number of simulation runs. For further information about the model the reader is referred to Yenigul et al., 2003.

A plan view of the model domain used in the numerical experiments is shown in Fig. 1. The overall dimensions of the domain are 300 m both in *x*- and *y*- directions. Nodal spacing, $\Delta x$ and $\Delta y$ are equal to 2 m in both directions. A landfill of 50 m by 100 m is located to the left of the model domain. Single row monitoring networks of 3 wells and 10 wells are located from 30 m to 180 m downgradient of the landfill with 30 m distance apart. It is considered that continues pumping takes place only at one monitoring well of each 3 well monitoring network. The aquifer is assumed to be confined, with a known constant hydraulic head at the left and right boundaries with a macroscopically constant hydraulic gradient of 0.001. The porosity of the medium is assumed to be 0.25. A geometric mean hydraulic conductivity of 2.23 m/day is considered and the variance of Y is set at $\sigma_y^2$= 0.6. The isotropic covariance of Y is chosen to be of exponential form with a correlation length, $\lambda$= 15 m.

Potential leak locations occur along the downgradient edge of the landfill (Figure 1). Leak is assumed to be continuous at a constant mass rate of 1 mg/l/day. Longitudinal dispersivity ($\alpha_L$) equals to 0.2 m while the ratio between $\alpha_L$ and $\alpha_T$ is assumed to be 1/10 (Bear, 1972). The threshold concentration (detection limit) at which detection occurs is set at 0.5% of the initial source concentration. Contaminants are assumed to be conservative and to be completely mixed over the depth of the aquifer. Pumping rates of 20 l/day, 40 l/day, 80 l/day and 120 l/day have been used in calculations in order to investigate the influence of the pumping rate on detection probability.

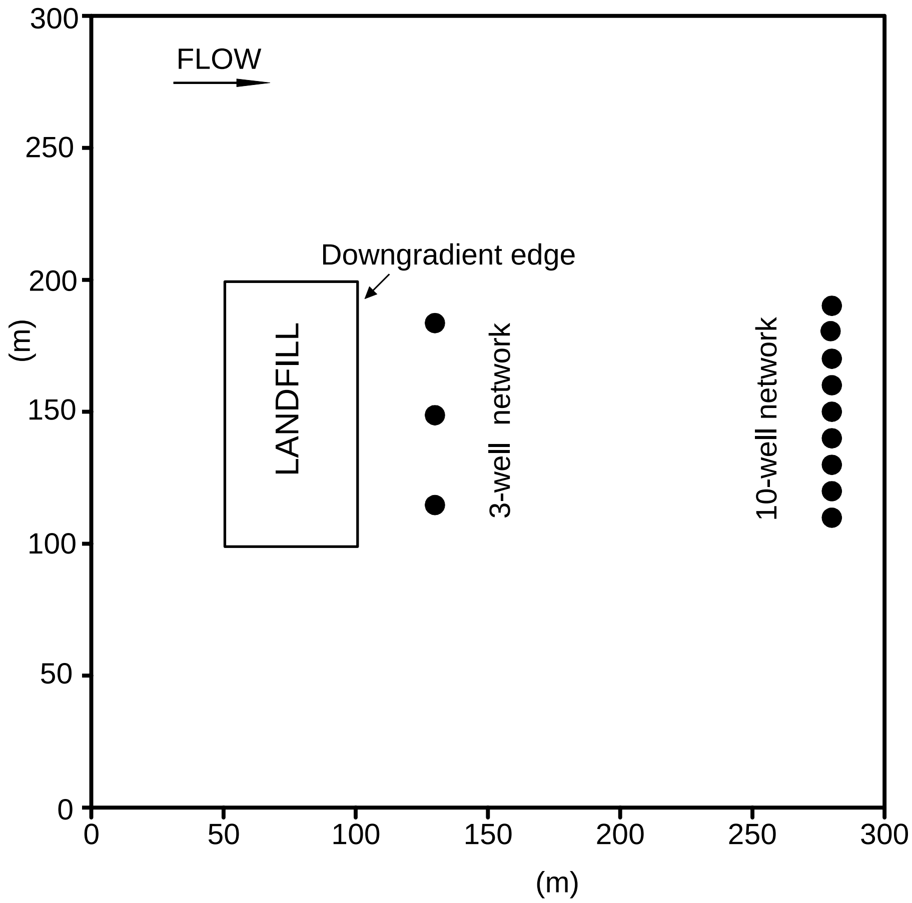


**Fig. 1** A plan view of model domain with selected single row monitoring networks.

## RESULTS AND DISCUSSIONS

700 Monte Carlo simulations are carried out for current monitoring method and for monitoring where continuous pumping from monitoring well takes place in order to determine whether the pumping from monitoring wells will improve the detection probability of the widely applied common practice that fulfils the minimum regulatory requirement (a monitoring network system of three downgradient wells) especially in a relative low dispersive media. Fig. 2 shows that the detection probability increases the distance from the landfill increases since the plume gets wider as it moves further away from the point it has originated. Therefore the maximum probability for both 3-well and 10- well monitoring networks is achieved 180 m away from the landfill. A 3-well network can maximum detect the 50% of the contaminant plumes while a 10-well monitoring network detects 87% of the plumes when the network is placed furthest away from the landfill.

However, Fig. 3 shows that 56.7% of the contaminant plumes are detected 60 m away from the landfill when one of the well of a 3-well monitoring network is pumped continuously even with a quite small pumping rate of 40 l/day. The detection probability of the 3-well monitoring networks increase as the pumping rate increases and detection occurs closer to the landfill. With a pumping rate of 120 l/day all of the plumes released from the landfill can be detected 60 m away from the landfill in a relatively low dispersive heterogeneous media.

The maximum detection probability achieved with a 10-well monitoring network furthest away (180 m away) from the landfill can be achieved by a 3-well monitoring network 60 m earlier when continuous pumping with a rate of 80 l/day takes place in only one well of the network. Furthermore with a pumping rate of 120 l/day the detection probability of a 3-well monitoring network is higher than that of a 10-well monitoring network (with current monitoring method) even at the closest distance, namely, 30 m away from the landfill.

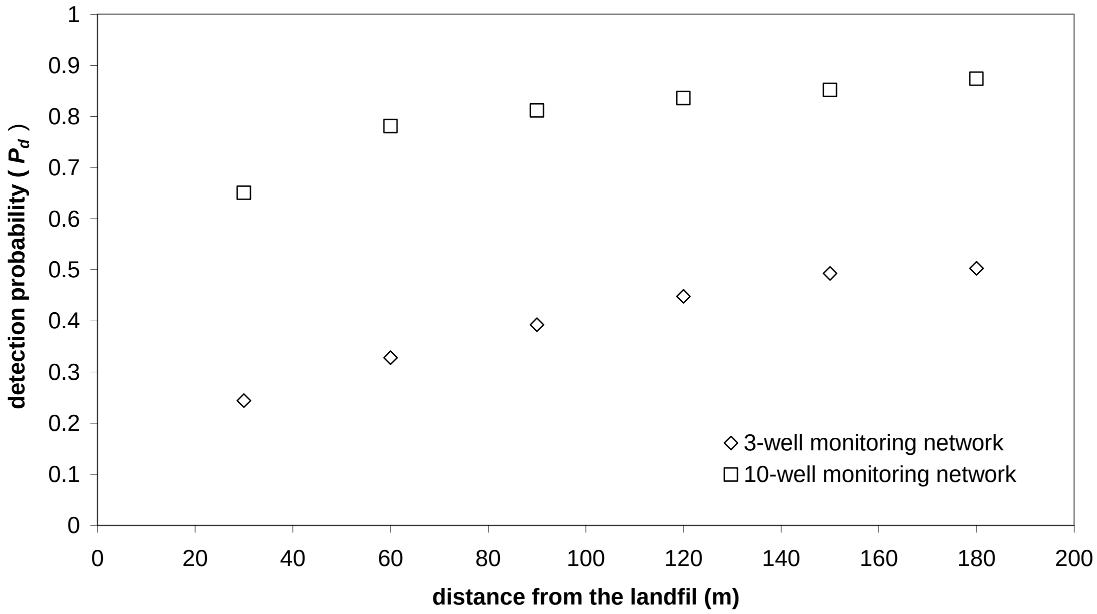


**Fig. 2** Detection probability of 3-well monitoring networks for current monitoring method.

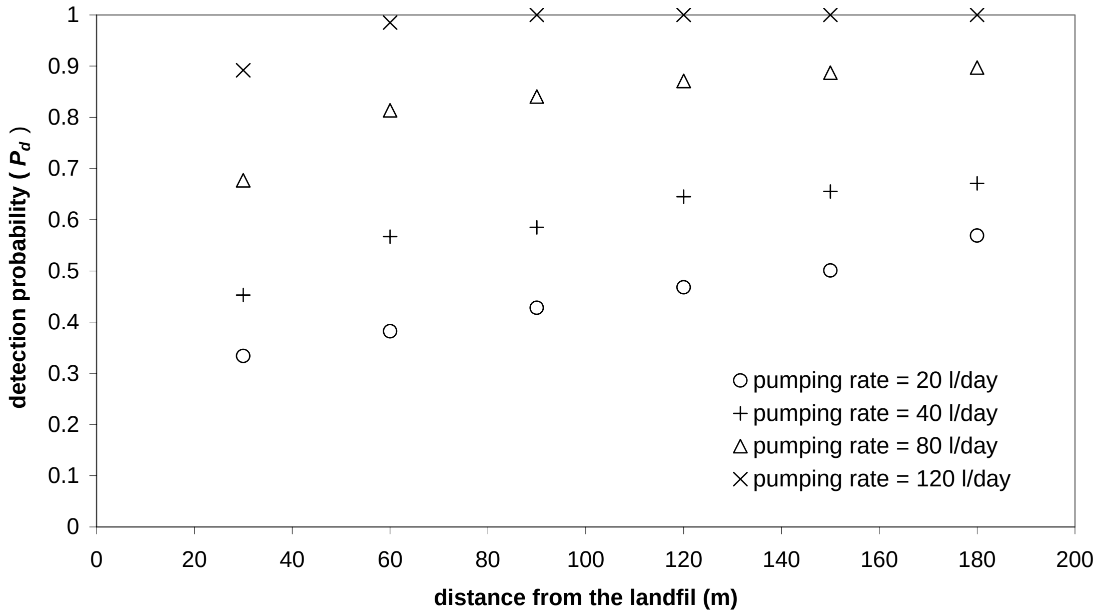


**Fig. 3** Detection probability of 3-well and 10-well monitoring networks for monitoring where continuous pumping from monitoring well takes place

## CONCLUDING REMARKS

The results of analysis shows that continuous pumping from the monitoring wells improve significantly the efficiency of the widely applied common practice that fulfils the minimum regulatory requirement (a monitoring network system of three downgradient wells) in low dispersive medium. The detection probability increases as the pumping rate increases. However, the increase in the pumping rate will not make any further improvement once 100 % reliability is achieved at a certain pumping rate. The same detection probability level can be achieved by monitoring network composed of more wells when current monitoring method is applied. However it will happen still further away compared to monitoring method including continuous pumping from the monitoring wells. This will most likely make a significant difference in efficiency of monitoring networks when early detection is the second criterion beside the maximizing detection probability.

**Acknowledgements** This research is funded by DIOC Water (Delft Interfacultair Onderzoeks Centrum voor de duurzaam gebouwde omgeving), of the Delft University of Technology. The financial support is gratefully acknowledged.

## REFERENCES

Bear, J. (1972) Dynamics of Fluid in Porous Media. New York: American Elsevier.

Chen P.H., And Wang C.Y. (1997) Investigation Into Municipal Waste Leachate In The Unsaturated Zone Of Red Soil. 23 (2): 237-245.

Elfeki, A.M.M. (1996) Stochastic Characterization of Geological Heterogeneity and Its Impact on Groundwater Contaminant Transport. Ph.D. diss, Delft University of Technology, Delft, The Netherlands.

European Community Council (ECC). (1999) Directive on the landfill of waste. Official Journal L.

Haug, A., Petrini, R.H., Grisak,G.E, Klahsen, K. (1989) Application of Geostatistical Methods to Assess Position and Spacing of Groundwater monitoring wells. Proc., Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection and restoration, National Water Well Association.

Heron, G., Bjerg, P.L., Gravesen, P., Ludvigsen, L., And Christensen, T.H. (1998) Geology And Sediment Geochemistry Of A Landfill Leachate Contaminated Aquifer (Grinsted, Denmark) Journal Of Contaminant Hydrology. 29: 301-317.

Hudak, P.F., and Loaiciga, H.A. (1993) A Location Modeling Approach for Groundwater Monitoring Network Augmentation. Water Resources Research 29 (8): 643-649.

Hudak, P.F. (2000) Efficiency comparison of graphical approaches for designing contaminant detection networks in groundwater. Water Resources Research, vol.38, no. 12: 18.1-18.5.

Mato, R.R.A.M. (1999) Environmental Implications Involving The Establishment Of Sanitary Landfills In Five Municipalities In Tanzania: The Case Of Tanga Municipality, Roirces. Jour. Conservation And Recycling. 25:.1-16.

Mikac, N., Cosovic, B., Ahel, S.A., And Toncic, Z. (1998) Assessment Of Groundwater Contamination In The Vicinity Of A Municipal Waste Landfill (Zagreb, Croatia). Water Sciences Technology. 37(8): 37-44.

Meyer, P.D, A.J. Valocchi, and J.W. Eheart. (1994) Monitoring Network Design To Provide Initial Detection of Groundwater Contamination. Water Resources Research, vol. 30, no. 9: 2647-2659.

Morisawa, S., And Inouue, Y. (1991) Optimum Allocation Of Monitoring Wells Around A Solid-Waste Landfill Site Using Precursor Indicators And Fuzzy Utility Functions, Journal Of Contaminant Hydrology, Vol. 7, pp. 337-270.

Riedeker, S., Suter, J.F.m., and Giger W. (2000) "Benzene and Naphthalenesulfonates in leachates and plumes of Landfills", Water Resources. 34 (7): 2069-2079

Rouhani, S., and T.J. Hall (1988) Geostatistical Schemes for Groundwater Sampling. Journal of Hydrology, vol. 81, no. 1: 85-102.

Storck. P., J.W. Eheart, and A.J. Valocchi. (1997) A method for optimal location of monitoring wells for detection of groundwater contamination in three-dimensional heterogeneous aquifers. Water Resources Research, vol. 33, no. 9: 2081-2088.

U.S. Environmental Protection Agency (USEPA) (1986) RCRA Groundwater Monitoring Technical Enforcement Guidance Document.

Yenigul, N.B., A.M.M. Elfeki, J.C. Gehrels, C. van den Akker, A.T. Hensbergen, and F.M. Dekking. (2004) Reliability Assessment Of Groundwater Monitoring Networks At Landfill Sites. Journal of Hydrology. In Press.