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# Influence of Uncertainty in Leak Location on Detection of Contaminant Plumes Released at Landfill Sites

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**Abstract:** Landfills represent a significant threat to groundwater contamination due to their nature of operation and their abundance. Monitoring well networks at these sites are of vital importance in detecting leakage plumes. Efficiency of the monitoring system significantly depends on many factors including subsurface heterogeneity, nature of the landfill, numbers of wells and so forth. However, in the presented study, the main focus is the uncertainty in leak locations and the influence of plume size on the detection probability. A Monte Carlo simulation coupled with groundwater flow and a random walk particle-tracking model has been used to simulate contaminant plumes released from landfills. It has been observed that detection probability increases as the size of the initial contaminant leak source and dispersivity of the medium increases.

## INTRODUCTION

Contaminants are introduced in groundwater by planned human activities rather than by the natural phenomena. Landfills, storage and transportation of commercial materials, mining, agricultural operations, interaquifer exchange and saltwater intrusion are the major source of groundwater contamination. Among these, landfills represent a widespread and significant threat to groundwater quality, human health and moreover some of the ecosystems, due to their very nature of operation and abundance. Unfortunately, in many places the environmental impact of the landfill leakage, particularly on groundwater quality, has been encountered several times to date regardless of an ideal site selection and well design. Such examples have been presented in works by Chen and Wang (1997), Mato (1998), Heron et al. (1998), Mikac et al (1998) and, Riediker et al. (2000). The 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. However, it is often difficult to ensure that a specific network will detect all of the contaminants released from the landfill because of the numerous significant uncertainties that are involved. 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

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are the uncertainties that have great influence on detection probability of contaminant plumes or, in other words the efficiency of monitoring networks.

In practice monitoring network design is controlled and structured by institutional regulations. European Community and U.S. Environmental Protection Agency (USEPA) regulations are most widely recognized and applied in many countries. These regulations require installation of sufficient detection-monitoring wells that can detect a contaminant leak before it crosses the compliance boundary. Minimum requirements are three downgradient wells, one upgradient well and a compliance boundary, which may be up to 150 m from the landfill. 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. There is no recognition of the uncertainty in this requirement contrary to the reality.

Although not all the relevant factors have been incorporated to solve the detection-monitoring problem, several authors have illustrated different aspects of this complex problem. In general the approaches based on geostatistical methods, optimization methods and methods based on extensive simulation are used. For instance, Rouhani and Hall (1988) investigated the significance of sampling program in network design by using a method based on variance reduction analysis, media ranking and risk. In another study, Haugh et al. (1989) presented a geostatistical method to assess the positions and spacing of monitoring wells along the edge of a waste management facility. Geostatistical tools are used efficiently, but neither groundwater flow nor contaminant transport models were considered in both studies. Massmann and Freeze (1987) focused on a risk-cost-benefit analysis for waste management facility in the perspective of the owner/operator to make design decisions for facility. Hudak and Loaiciga (1993) presented a multiobjective method that can be used to locate wells to provide detection of contamination but they did not considered uncertainty in their approach.

In the work of Meyer et al. (1994), a multiobjective stochastic optimization approach is used to determine the 2D location of monitoring wells The method incorporates uncertainty in hydraulic conductivity and source location through Monte Carlo simulations. Storck et al (1994) extended this model to three dimensions. Conversely, Angulo and Tang (1999) approach the detection-monitoring problem from a decision analysis perspective.

The focal point of this study is to investigate the influence of uncertainty in contaminant leak location and medium dispersivity on the detection probability. Meanwhile the influence of subsurface heterogeneity and number of wells have also been examined. In addition to previous works in the literature, this study includes size effect of the contaminant leak source on the detection probability.

## PROCEDURE AND MODEL DESCRIPTION

A two dimensional generic model is used to perform the numerical tests. The regulations and common current practice have been considered to set up the hypothetical model. A Monte Carlo simulation coupled with a two dimensional steady state groundwater flow and a random walk particle-tracking model (Elfeki, 1996) has been used to simulate contaminant plumes released from landfills.

Monte Carlo method is used to generate multiple leak locations with a uniform distribution within the landfill. A local failure in the liner (impervious layer of clay or geotextile), which occurs at a random location within the area covered by the landfill, has been taken into account. The size of the plume is an important factor that affects the detection probability since if the plume is bigger the easier it can be detected. In this study it has been considered that the extent of the plume is highly related to the initial size of the contaminant source and the dispersivity of the medium. Therefore to analyze the influence of the initial contaminant source size, the local failure is modeled not only as a point source but also as a small areal source (equal to a grid cell size). Furthermore, in order to examine the influence of dispersivity, the pore-scale longitudinal dispersivity ($\alpha_L$) was set to 0, 0.5 and 1.5 m respectively. The ratio between the transverse ($\alpha_T$) and longitudinal dispersivity ($\alpha_L$) is assumed to be 1/10 (Bear, 1972). 2000 particles are used in a particle tracking routine and contaminants are considered to be conservative. Monte Carlo simulations consist of 500 random plumes originating from random locations.

Subsurface heterogeneity is one of the most important factors that controls contaminant transport and hence the efficiency of monitoring systems. In this study, subsurface heterogeneity is reflected by the spatial variability of the hydraulic conductivity. Single realization of hydraulic conductivity has been generated and considered as a fixed field for the 500 random locations within the landfill. 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. The numerical experiments are executed for homogenous and heterogeneous media, respectively. A mean value of $\mu_Y$=2.20, and a correlation length of 5 m in both x- and y- directions have been used. Since the variance of ln(K), $\sigma^2_Y$, is one of the parameters that determines the degree of heterogeneity, its influence on the detection probability has been evaluated by setting $\sigma^2_Y$ values to “0” for the homogenous case and then to “1” and “2”, respectively, for heterogeneous cases.

A plan view of the model domain used in the numerical experiments is shown in Figure 1. The overall dimensions of the domain are 200 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 50 m is located to the left of the model domain. A single row monitoring system of ten wells is located 30 m downgradient of the landfill with an equal spacing of 6 m between each of them. 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.

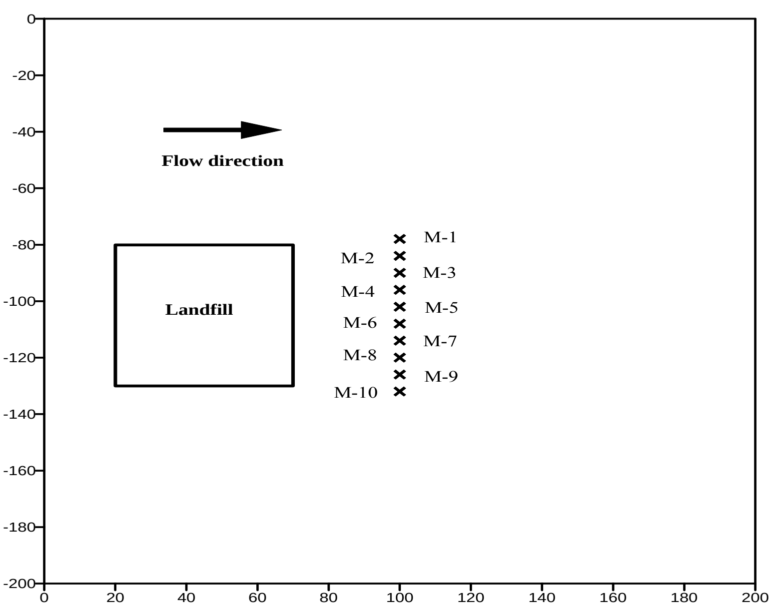


Figure 1 A plan view of model domain with selected single row monitoring system.

## RESULTS AND DISCUSSIONS

In several Monte Carlo simulations different combinations of $\sigma^2_Y$, $\alpha_L$, and size of the leak location have been tested. When one of these parameters was changed the others were kept constant for each numerical experiment, in order to determine the influences of each parameter on detection probability. The detection probability of each well has been calculated individually. However, single row monitoring systems, composed of three, five and all ten wells, have been considered to perceive the maximum detection probability of a monitoring system. In this case, early detection of the plume has been set as a criterion. Thus the earliest detection of the plume by only one of the wells determines the detection probability of a monitoring system.

For both point and small areal contaminant source cases, the effect of hydraulic conductivity variance on the detection probability of each well and on detection probability of single row monitoring systems of 3, 5 and 10 wells are shown in Figures 2, 3, 4 and 5, respectively. There is no explicit relation between detection probability of each well and the variance of hydraulic conductivity. However in case of detection probability of a system a general trend is observed. The detection probability increases as the variance decreases. This is because in a heterogeneous field plumes are rather following tortuous paths, becoming irregularly shaped and moving either above or below the point from which they originated. This implies a greater uncertainty in the pathways, in which plumes travel and hence makes them more difficult to detect. On the other hand, in a homogenous field plumes are much uniform in shape and tend to travel in a direction parallel to the average hydraulic gradient.

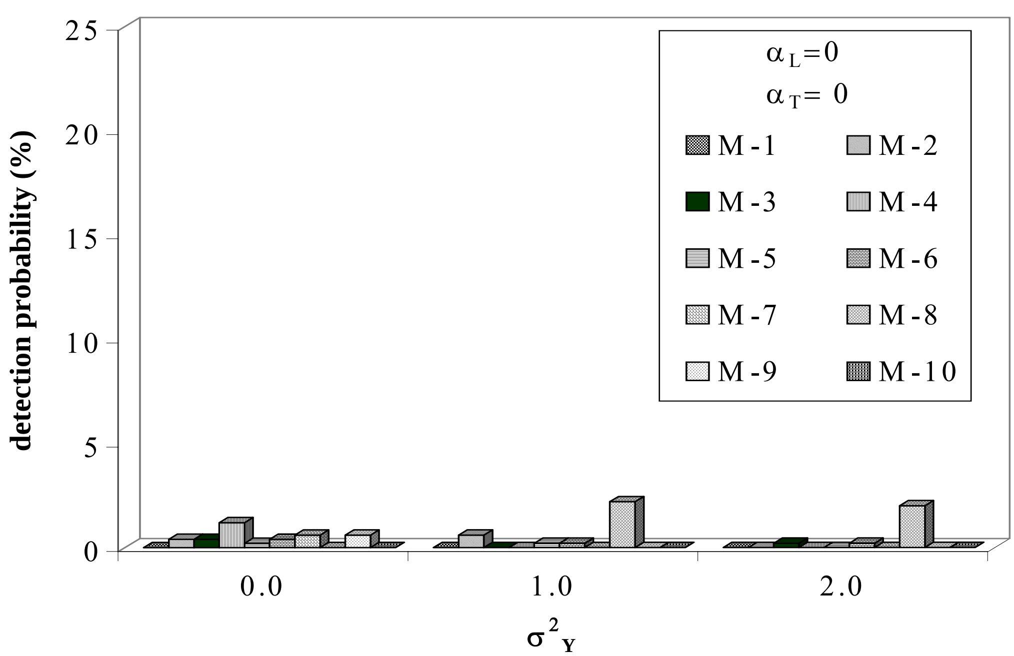
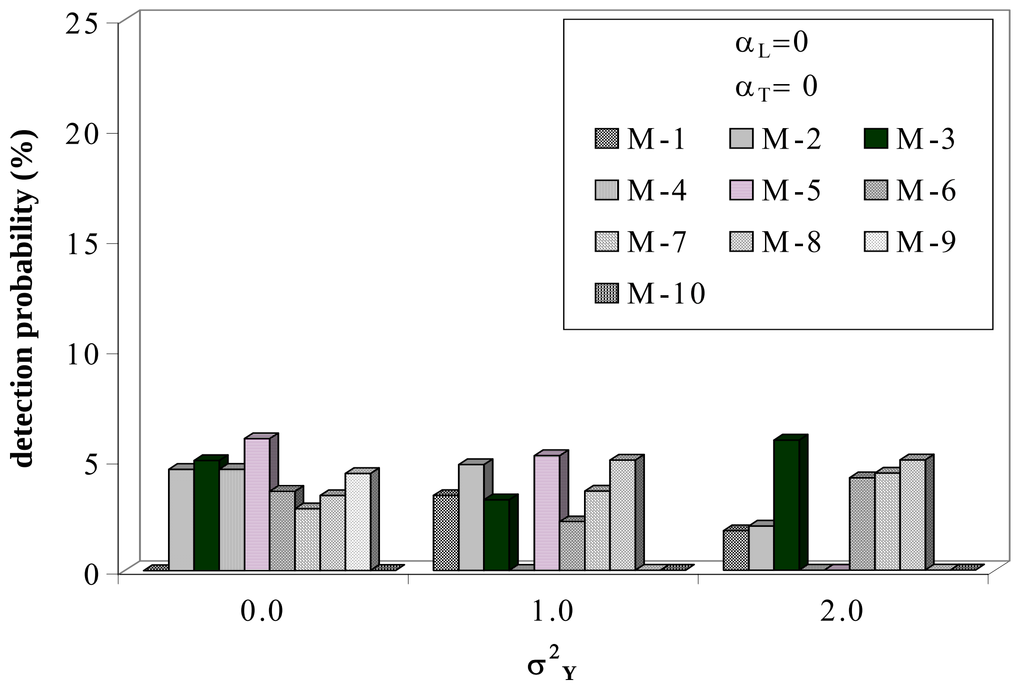


Figure 2. Influence of hydraulic conductivity variance on monitoring wells for point contaminant




source case.

Figure 3. Influence of hydraulic conductivity variance on monitoring wells for areal contaminant source case.

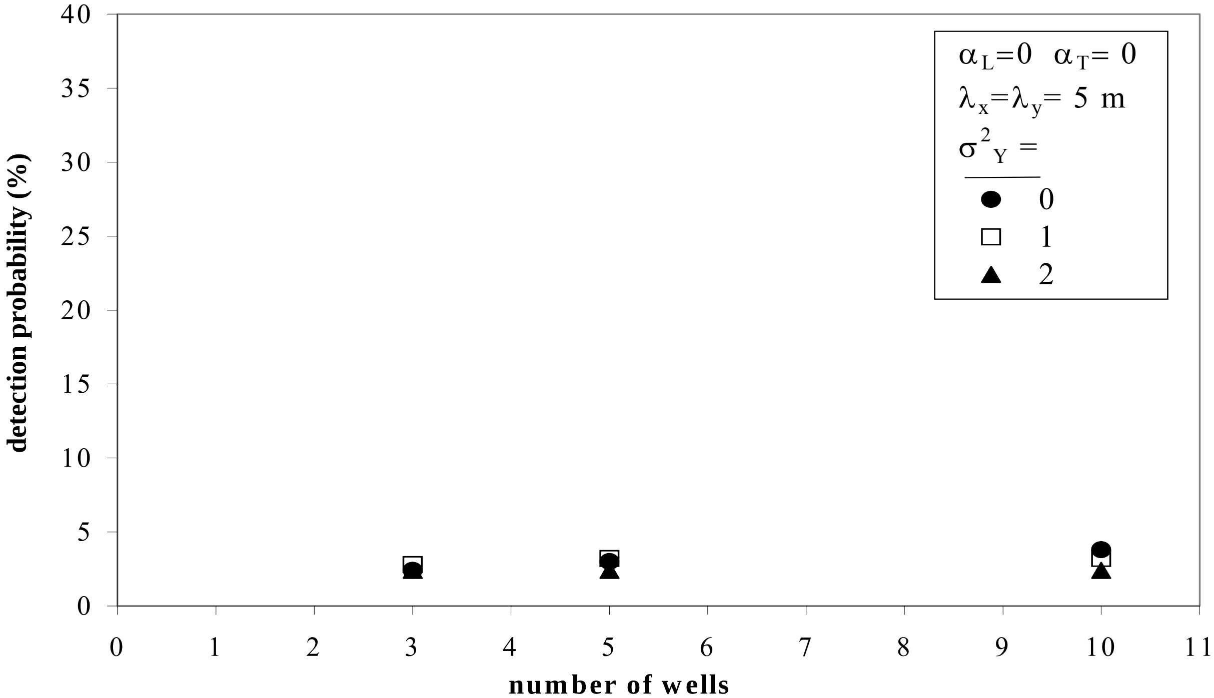



Figure 4. Influence of hydraulic conductivity variance on monitoring systems composed of 3, 5 and 10 wells for point contaminant source case.

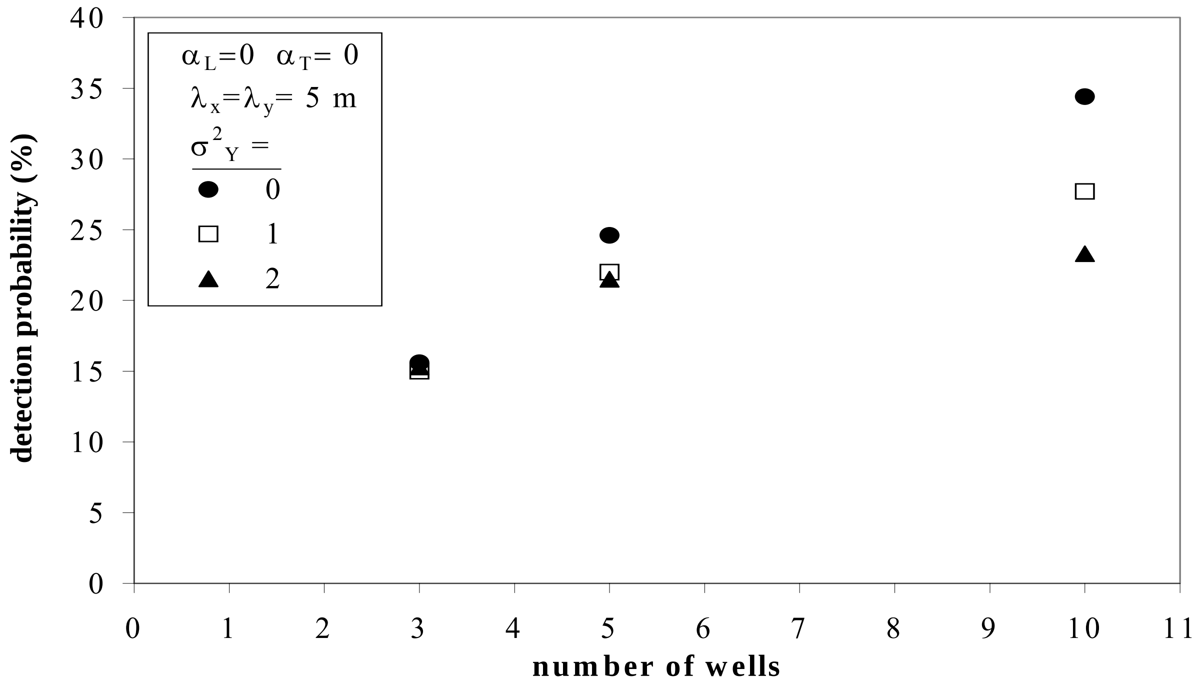



Figure 5. Influence of hydraulic conductivity variance on monitoring systems composed of 3, 5 and 10 wells for areal contaminant source case.

Results confirm that the dispersivity of a medium and initial size of the contaminant source have a great influence on the detection probability. Figures 6 and 7 show that the detection probabilities of the wells increase considerably as the dispersivity of the medium increases for both point and areal source cases. This is due to the fact that the plume broadens as the transverse dispersivity increases; hence each monitoring well can detect more plumes. The monitoring wells, which are able to detect very few plumes, or no plumes in advection case ($\alpha_L$=$\alpha_T$=0), detect much more plumes as the dispersivity of the medium increases (see Figures 2, 3, 6 and 7). Similarly, detection probability of the plume increases as the contaminant source size increases (see Figures 3 and 5) since the size of the leak dominates the width of the plume. Therefore, in both cases the detection probability of each well increases, and hence the detection probability of the monitoring systems consist of a number of well increases also.

Regarding monitoring systems in any case, detection probability increases as the number of the wells in the system increases. Nevertheless, as it is shown in Figure 8, even in a medium with rather high dispersivity and in a relatively large contaminant source case maximum 52 % of the plumes can be detected by a 3 well system, which is the current practice and requirement of the regulation. In the medium, which have very low or no dispersivity the detection probability reduces to 34 %. However, detection probability of a 10 well monitoring system can reach 100% in a medium with a high dispersivity.

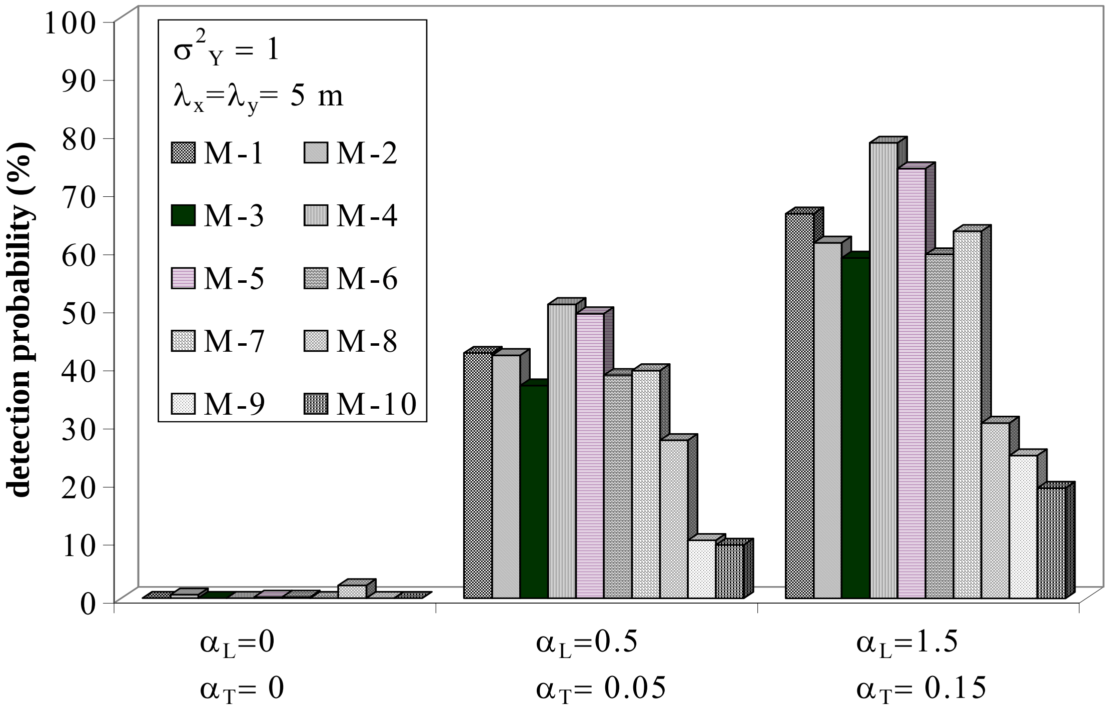



Figure 6. Influence of dispersivity of medium on monitoring wells for point contaminant source case.

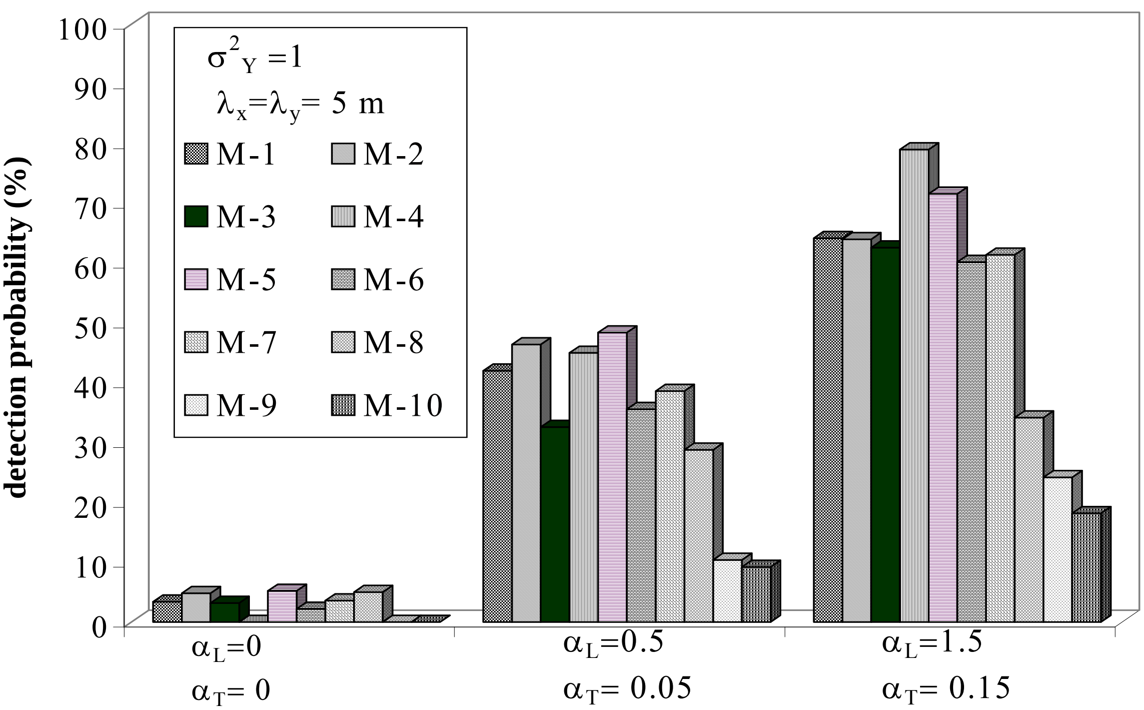



Figure 7. Influence of dispersivity of medium on monitoring wells for areal contaminant source case.

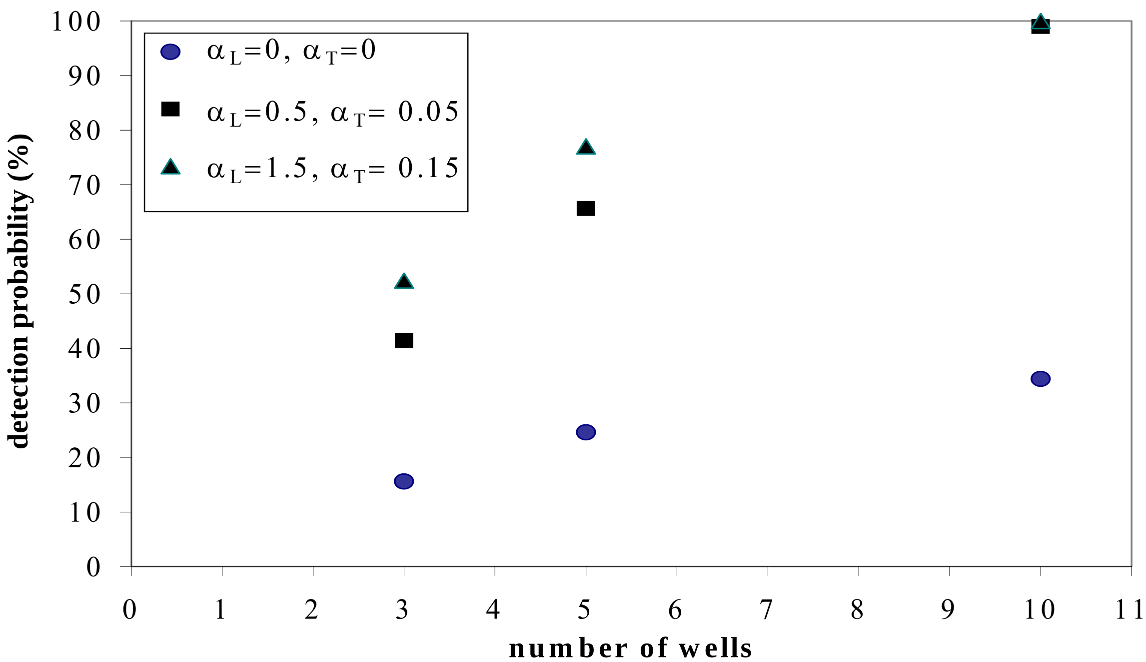



Figure 8. Influence of dispersivity of medium on monitoring systems composed of 3, 5 and 10 wells for areal contaminant source case ($\sigma^2_Y = 0$).

## CONLUDING REMARKS

The influence of various important parameters on the detection probability of contaminant plumes has been investigated. The results obtained in this study show that detection probability of contaminant plumes released from a landfill highly depends on size of the plume, subsurface heterogeneity, and the number of wells in a monitoring system. Since the contaminant plume widens as the dispersivity of medium and the initial size of the contaminant source increase, the detection probability increases. On the other hand, detection probability shows a tendency to decrease as the subsurface heterogeneity increases. Furthermore, the detection probability of the monitoring systems increases as the number of the wells in the system increases. Yet, the efficiency of 3 well system (of current practice), particularly in medium with relatively low dispersivity, is quite dubious.

## ACKNOWLEDGEMENT

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