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A new risk and stochastic analysis of monitoring and remediation in subsurface contamination

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Sanitary landfills constitute the most widely used management approach for the disposal of solid wastes because of their simplicity and cost effectiveness. However, historical records indicate that landfills exhibit a high failure rate of groundwater contamination. Successful detection of aquifer contamination via monitoring wells is a complicated problem with many factors, such as the heterogeneity of the geologic environment, the dispersion of contamination into the geologic medium, the quantity and nature of the contaminants, the number and location of the monitoring wells, and the frequency of sampling, all contributing to the uncertainty of early detection. Detection of contaminants, of course, is of value if remedial actions follow as soon as possible, so that the volume of contaminated groundwater to be treated is minimized. Practically, there is always a time lag between contaminant detection and remedial action response. Administrative decisions and arrangements with local contractors initiate remedial procedures introduces a time lag between detection and remediation time. During this time lag a plume continues to move into an aquifer contaminating larger groundwater volumes. In the present study these issues are addressed by investigating the case of instantaneous leakage from a landfill facility into a heterogeneous aquifer. The stochastic Monte Carlo framework was used to address, in two dimensions, the problem of evaluating the effectiveness of contaminant detection in heterogeneous aquifers by linear networks of monitoring wells. Numerical experiments based on the random-walk tracking-particle method were conducted to determine the detection probabilities and to calculate contaminated areas at different time steps. Several cases were studied assuming different levels of geologic heterogeneity, contamination dispersion, detectable contamination limits and monitoring wells' sampling frequencies. A new perspective is introduced for the correction of risk analyses; contemporary risk analyses consider the cost of alternative remediation procedures by assuming that the contamination area to be remediated coincides with the area calculated at the time of detection. However, there is always a considerable lag between the time that a plume is detected and the time when remediation commences. This time lag constitutes a random variable that depends on available resources and technologies, as well as efficiency of administration decision-making. An expression is proposed that accounts for the delay between detection and remedial action in order to provide a correction to decision analyses that evaluate the economic worth of well monitoring. This expression illustrates that delays over 3 years are equivalent to reducing the monitoring performance of 12 wells to that of a much lower number of wells, or equally, having to consider higher failure costs than those assumed in current risk analyses.