BARRIER-CONTROLLED MONITORED NATURAL ATTENUATION

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Abstract: Three existing technologies (source containment, source reduction, and monitored natural attenuation) are integrated in barrier-controlled monitored natural attenuation (BCMNA) – a new approach for managing plumes of contaminated ground water and remediating contaminated sites. The basic BCMNA concept uses a low-permeability, non-reactive barrier to release contaminants into an aquifer at a rate that optimizes natural attenuation. A simplified, one-dimensional model of the process is developed and a hypothetical example of BCMNA is presented for a site contaminated with benzene. The analytical solution is used to demonstrate how benzene concentrations can be controlled at a downgradient point of environmental compliance by manipulating design variables. BCMNA provides a greater degree of process control and risk reduction than monitored natural attenuation alone. BCMNA also holds promise for reducing remediation costs because 1) barriers can be constructed relatively inexpensively and 2) a cost-effective amount of source reduction can be applied inside the contained area with the BCMNA system remaining in place to safely complete the remediation process after source reduction is terminated. Further numerical modeling and a demonstration project are recommended to address important details and prove the concept.

In BCMNA, a vertical barrier with low hydraulic conductivity is constructed around a source of contaminated ground water. By applying hydraulic control inside the contained region, the contaminant can be metered out of the source area at a rate that takes maximum advantage of the natural attenuation capacity of the surrounding aquifer to reduce contaminant concentrations to safe levels at a downgradient point of compliance (POC). While the barrier and monitored natural attenuation (MNA) are being used to control the contaminant concentration downgradient, a cost-effective amount of source reduction can be applied within the contained area to reduce the total cleanup time. Figure 1 shows how this can be accomplished at a site where MNA alone is inadequate to achieve site-specific remediation goals. The water table level inside the contained source area is adjusted so that the natural attenuation capacity of the surrounding aquifer can accommodate the flux of contaminant out of the barrier. If the source concentration is reduced over time, the optimal flux rate through the barrier can be maintained by raising the water level inside the contained area by adding clean water from an external source.

In this way, albeit slowly, the process can be allowed to continue until the concentration in the source area is reduced sufficiently that MNA alone is capable of handling the contaminant, at which time the barrier could be breached. Should it be desired to speed up the remediation process, an appropriate engineered source reduction technology can be employed to reduce the mass and concentration within the contained region, if this is technically feasible. Incorporating some level of engineered source reduction into the BCMNA approach is not a requirement, but this may be considered to reduce the time necessary for remediation.

In this paper, a one-dimensional model is developed and applied to a hypothetical example to illustrate the operation of a BCMNA system. The contaminant is benzene with a source area concentration, C_S, of 10,000 μg/L. The POC is 450 m downgradient from the barrier, and the maximum contaminant level, C_{MCL}, at the POC is 5 μg/L. A stable benzene plume emanates from the source, but the natural attenuation capacity of the aquifer is insufficient to meet the regulatory requirement at the POC without additional engineered measures.

The analytical solution was used to calculate contaminant concentrations in the aquifer downgradient from the barrier for four different head losses, Δh, across the barrier. The results are shown in Figure 2, together with the concentration profile in the aquifer without a barrier. In all cases, the contaminant concentration decreases with distance from the source according to the natural attenuation capacity of the aquifer. When no barrier is employed, the contaminant is released into the aquifer at the greatest rate, and the concentration at the POC is about 25 times the C_{MCL} for the conditions of this example. With a barrier in place around the source, the contaminant flux into the aquifer and the concentration at the POC both decrease as the head loss across the barrier decreases. When the head loss is 0.3 m, the concentration at the POC is slightly less than the C_{MCL}. Further reductions in the concentration at the POC can be achieved by smaller head losses across the barrier. For example, when the head loss across the barrier is 0.1 m, the concentration at the POC is about 3 times smaller than the C_{MCL}, as shown in Figure 2. While a head loss of 0.1 m produces a greater degree of safety at the POC, it also underutilizes the natural attenuation capacity of the aquifer.

Benefits of BCMNA include risk reduction and cost savings. Presently, MNA without a barrier has only a limited factor of safety. The release of contamination from the source area into the ground water is uncontrolled and difficult to predict, even with abundant data and a sophisticated model. Monitoring of contaminant concentrations in ground water is the only safeguard at MNA sites without barriers. With the BCMNA technology, monitoring of contaminant concentrations in ground water still would be necessary, but the rate of release from the source area would be controlled and adjusted on a periodic basis to achieve design and remediation goals. Thus, BCMNA would reduce the risk of failure relative to the current state of practice for employing MNA-based strategies.

In addition, cost savings are anticipated because vertical barriers, such as soil-bentonite walls, are relatively inexpensive and because the barrier permits optimization of the remediation process in two ways: 1) the flux of contaminant out of the barrier can be adjusted to utilize the maximum natural attenuation capacity of the aquifer and 2) the most cost-effective amount of active source reduction can be applied within the contained area. Active source reduction is subject to the law of diminishing returns, and the BCMNA system provides a means to safely complete the remediation process after source reduction is no longer cost effective.

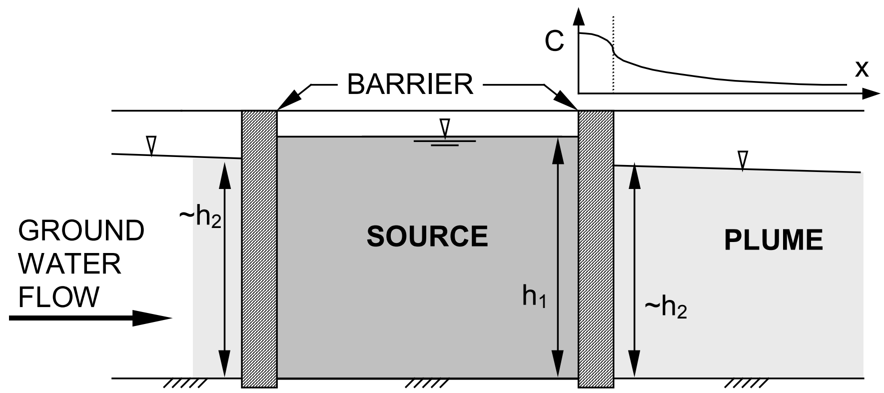

FIGURE 1. Cross-sections of barrier-controlled MNA near the source area.

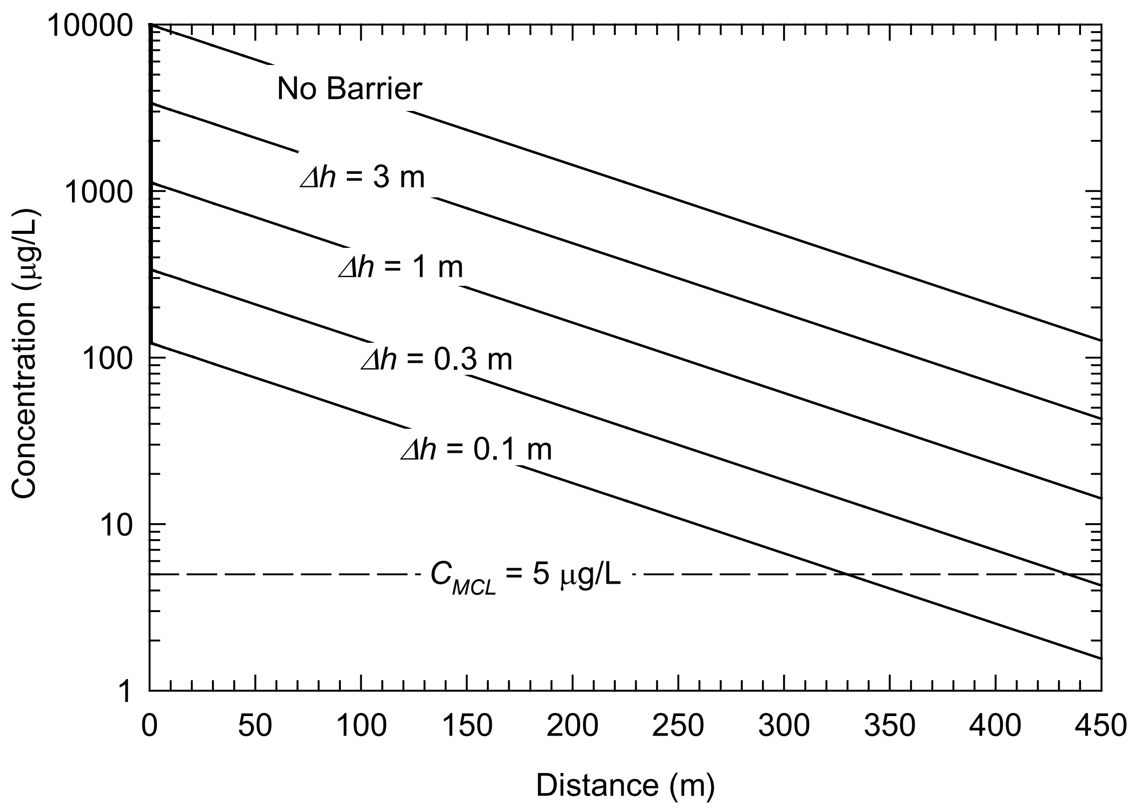

FIGURE 2. Benzene concentrations in the aquifer downgradient from the source area as a function of head difference across the barrier.