Contaminant Transport through Composite Geomembrane-Soil-Bentonite Cut-Off Walls

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Abstract
Composite geomembrane-soil-bentonite (CGSB) cut-off walls are recognized to be effective hydraulic barriers. Although the hydraulic effectiveness of a CGSB wall can be indicative of contaminant transport past the wall, contaminants can also diffuse through the wall. In this paper, transport of organic and inorganic contaminants past CGSB walls were determined using results from a groundwater flow model and an analytical model for diffusion in CGSB cut-off walls. Results of the analyses show that the predominant pathways for contaminant transport past CGSB walls depend on the type of contaminant being contained and the hydraulic effectiveness of the wall. Even for hydraulically effective CGSB walls, organic contaminants can diffuse through the wall. Therefore, the effects of diffusion should be considered in analyses of the performance of CGSB walls.

CGSB walls can be used to reduce contaminant transport from a contaminated site or to reduce the rate of migration of uncontaminated groundwater onto a site, which can drive contaminants off-site. For cases in which the objective of the cut-off wall is to reduce off-site contaminant migration, contaminant transport past the wall must be evaluated. Analytical methods based on solutions to the advection-dispersion equation are available for evaluating contaminant transport through soil-bentonite walls (e.g. Rubin and Rabideau 2000). However, these methods are not applicable to CGSB walls because they do not take into account the complex pathways of flow and contaminant transport past these types of walls.

There are three pathways for contaminant transport past CGSB walls: (1) through defects or poor seams in the geomembrane component of the CGSB wall, (2) beneath the CGSB wall, and (3) diffusion through the CGSB wall (Fig. 1). Steady-state contaminant transport through defects or poor seams in the geomembrane component of a CGSB wall is dominated by advection for soil-bentonite mixtures having a hydraulic conductivity of 1×10^{-7} cm/s and a unit gradient (Daniel and Koerner 2000). Steady-state contaminant transport beneath a CGSB wall is also likely to be dominated by advection, given the long pathway for contaminant transport.

Geomembranes are essentially impervious to diffusion of inorganics. In contrast, volatile organic compounds (VOCs) can rapidly diffuse through a geomembrane. Steady-state diffusion through the intact CGSB wall can be computed using analytical methods developed by Foose et al. (1999) for predicting diffusion in composite liners. For typical CGSB walls (thickness=90 cm), the effect of the geomembrane on diffusion of VOCs through the wall is negligible and can be ignored in analysis with little resulting error (Foose et al. 1999). Thus, the steady-state mass flux via diffusion can be calculated using Fick's 1[st] law, with the diffusion coefficient and porosity of the soil-bentonite mixture as inputs.

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Results from groundwater flow models developed by Tachavises and Benson (1997a and b) for evaluating the hydraulic effectiveness of CGSB walls were used to evaluate the significance of different pathways for contaminant transport in CGSB walls. Tachavises and Benson (1997a and b) evaluated a 90-cm-thick 30-m-deep CGSB wall emplaced in an aquifer overlying a 30-m-thick less permeable aquitard. The porosity of the soil-bentonite mixture was assumed to be 0.4 and the hydraulic conductivity of the soil-bentonite mixture was $1x10^{-7}$ cm/s. The effects of defective joints in the wall were simulated by assuming defective joints had a hydraulic conductivity of $1x10^{-4}$ cm/s. The effects of areas of the soil-bentonite mixture having a hydraulic conductivity $>1x10^{-7}$ cm/s, or windows, were included in the model and were assumed to line up with defective joints. The hydraulic conductivity of the aquifer was $1x10^{-2}$ cm/s and the hydraulic conductivity of the aquitard was varied from $1x10^{-5}$ cm/s to $1x10^{-8}$ cm/s.

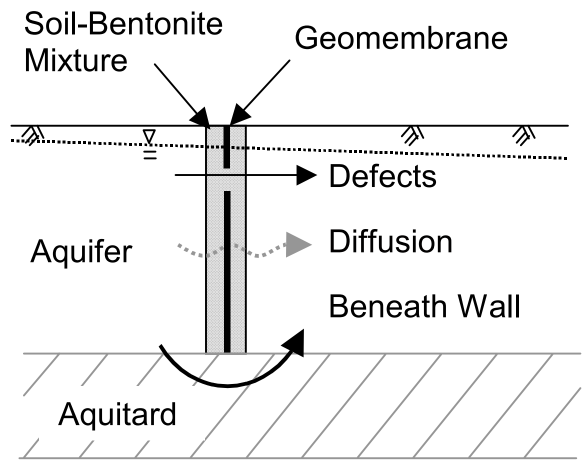

Fig. 1. Pathways of Contaminant Transport.

The steady-state mass flow rates via advection through defects in and beneath the CGSB wall were computed as the product of the mass concentration and the flow rate via each pathway. For the following analyses, a well constructed CGSB wall is assumed to have a defective joint fraction <10% and no windows or windows having a hydraulic conductivity of $1x10^{-5}$ cm/s. The concentrations of inorganic and VOCs solutes at the upstream face of the wall were assumed to be and 100 μg/L and spatially invariant. The concentration at the effluent face of the wall was assumed to be zero.

Graphs of the ratio of the mass flow rate of an inorganic solute through defective joints (J_{defect}) to the total mass flow rate (J_{total}) as a function of the defective joint fraction are shown in Fig. 2. The pathways for transport of an inorganic solute are through defects in the seams between geomembrane panels and seepage beneath the wall. For well constructed CGSB walls in intimate contact with an aquitard having a hydraulic conductivity of $1x10^{-5}$ cm/s, more than 80% of the contaminant flow is beneath the wall. If the hydraulic conductivity of the aquitard is $1x10^{-8}$ cm/s, less flow occurs beneath the wall and more than 70% of the contaminant flow is through defects. Therefore, for more permeable aquitards, contaminant transport beneath the wall should be included in analyses related to design and evaluation of CGSB walls. For low hydraulic

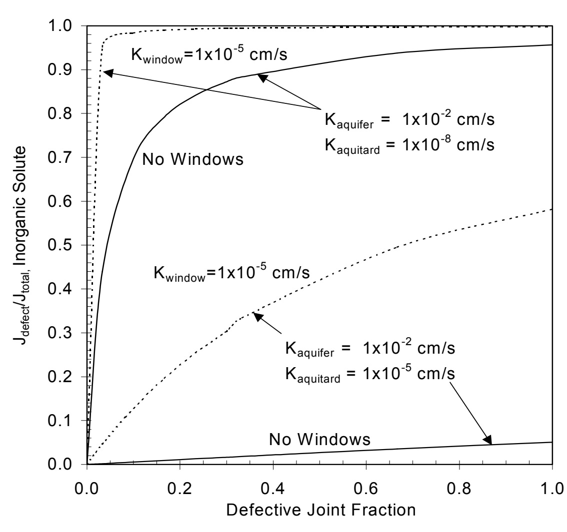

Fig. 2. Mass Transport of Organic Solute.

conductivity aquitards, contaminant transport analyses should include transport through defects in the wall. For cases in which the hydraulic conductivity of windows is >1x10^{-4} cm/s and defective joints exist, nearly all contaminant transport occurs through defects, regardless of the hydraulic conductivity of the aquitard.

The ratio of the mass flow rate of a VOC solute via diffusion ($J_{diffusion}$) to the total mass flow rate past the wall as a function of the defective joint fraction is shown in Fig. 3. The pathways for transport of a VOC solute are through defects in the seams between geomembrane panels, seepage beneath the wall, and diffusion through entire face of the wall. For well constructed CGSB walls in intimate contact with an aquitard having a hydraulic conductivity of 1x10^{-5} cm/s, 15% to 20% of the contaminant transport is due to diffusion through the wall. Of the remaining contaminant flow, 80% is beneath the wall. If the hydraulic conductivity of the aquitard is 1x10^{-8} cm/s, less flow can occur beneath the wall and more than 60% of the contaminant transported past the wall is due to diffusion through the face of the wall. If the wall is perfectly constructed and the hydraulic conductivity of the aquitard is 1x10^{-8} cm/s, >95% of the mass transport past the wall is due to diffusion. Therefore, diffusion of VOCs through the wall can be a significant pathway for contaminant transport past the wall and diffusion should be included in evaluations of the performance of CGSB walls.

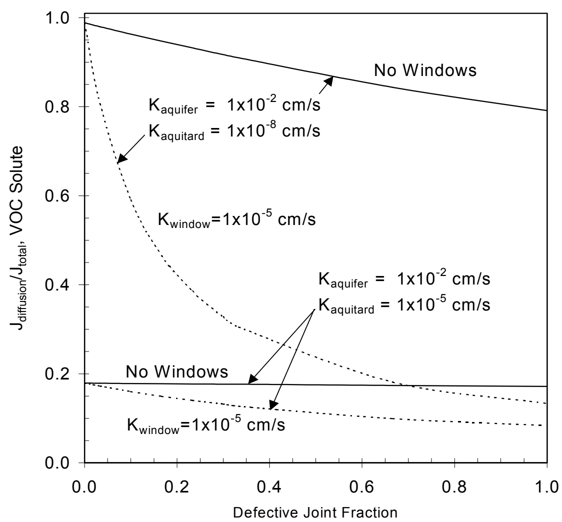

Fig. 3. Mass Transport of VOC Solute.

When evaluating contaminant transport past CGSB walls, it is essential to consider all significant pathways of contaminant transport. For inorganic solutes, the mass flow rate beneath the wall can be a significant pathway of contaminant transport and should be included in analyses. This is particularly true for relatively permeable aquitards. For VOC solutes, diffusion through the face of the wall can be the dominant pathway for contaminant transport, depending on the concentration of the solute and characteristics of the wall and aquitard.

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