Probabilistic Design of Permeable Reactive Barriers

by

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ABSTRACT: Deterministic design procedures, while adequate for feasibility evaluation, are not sufficient for final design of iron permeable reactive barriers (PRBs). A probabilistic design methodology is outlined, which incorporates not only probabilistic inputs for site characterization data, but also parent and daughter VOC degradation parameters. A multi-specie first order volatile organic compound (VOC) degradation model coupled with a probabilistic model is used for design of a zero-valent iron reactive permeable barrier for remediation of groundwater contaminated with high levels of VOCs (~5,000 ppb of tetrachloroethylene (PCE), ~50,000 ppb of trichloroethylene (TCE), ~5,000 ppb of 1,1-dichloroethylene (1,1-DCE), and other VOCs at lower concentrations). The PRB probabilistic design model allows for variability of site formation hydraulic conductivity, groundwater flow gradients, VOCs concentration levels, VOC degradation half-lives and degradation pathways from iron column test data, PRB installed thickness and iron PRB porosity. The PRB probabilistic model 85-percentile VOC effluent concentration levels are used to determine the minimum iron PRB average-effective thickness required to bring VOC concentrations to below MCLs. Input data sensitivity analysis is performed to quantify the impact of parameters variability on overall system performance. Quality control verification methods are especially important for PRB construction to verify in situ placed geometry and the PRB's minimal impact on the groundwater flow regimes. Direct in situ sampling of an undisturbed iron PRB can be difficult at depth and/or in flowing ground conditions. Driven probe techniques utilizing electrical resistivity and magnetometer are proposed as viable methods to determine PRB geometry, and hydraulic pulse interference tests are proposed to quantify the hydraulic impact of the PRB on groundwater flow regimes.

SITE BACKGROUND

A former manufacturing facility in Virginia was contaminated primarily with trichloroethene (TCE), Tetrachloroethene (PCE), and 1,1-Dichloroetene (1,1-DCE) in both the soils in the vadose zone and in the groundwater. Groundwater concentrations of TCE were detected up to levels of 50,000 ppb. The record of decision (ROD) was modified to a soil vapor extraction (SVE) system in the vadose zone for the soil remedy and an in situ iron permeable reactive barrier (PRB) for groundwater remediation. The remnant plume downgradient of the reactive barrier is expected to be in situ bio-remediated by flushing from the clean groundwater emanating from the PRB. The interbedded upper sands, silts and clays that comprise the Yorktown/Eastover underlie the Site forming the uppermost unconfined aquifer which has a maximum thickness of approximately 40 feet beneath the Site and has a horizontal hydraulic conductivity ranging from $1x10^{-3}$ to $1x10^{-5}$ cm.sec. Underlying the upper aquifer, clays and silts that comprise the St. Mary's confining unit have an approximate thickness of at least 70 feet. An iron permeable reactive barrier and surface impermeable cap system is proposed to be constructed around and over the suspected source area. The surface impermeable cap limits infiltration and thus reduces the hydraulic gradients across the proposed PRB. The PRB alignment was selected to intersect groundwater flow from the suspected source area to the neighboring surface water streams. The cap system covers an area of approximately 4-1/2 acres, and the PRB extends 1,165 feet in length from a depth of 17 feet below ground surface (bgs) down to a total depth of 42 feet with an average iron thickness of 4 inches.

PROBABILISTIC DESIGN METHODOLOGY AND ANALYSIS

The design methodology for the groundwater remedy involved a probabilistic design approach as outlined in Hocking et. al. (1998) and further refined to incorporate both the degradation of VOCs within the PRB and by natural attenuation mechanisms active downgradient of the PRB.

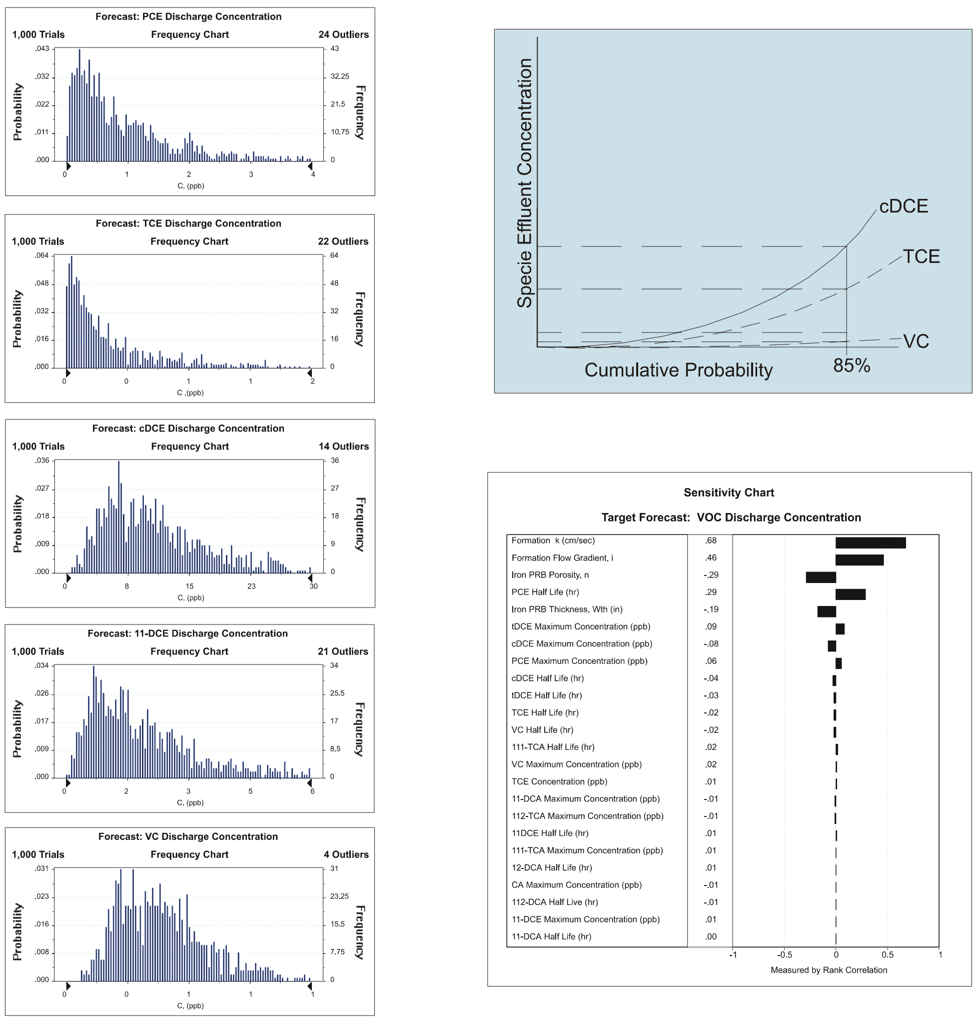

FIGURE 1. PRB Probabilistic Design Analysis Output Data.

The iron PRB is designed for influent concentrations that in combination with natural attenuation (NA) (biodegradation, dispersion, absorption, etc.) mechanisms would meet target concentrations at a pre-determined Site Compliance Point (SCP). This proposed design methodology (Hocking and Ospina, 1999) has been utilized at a number of Superfund sites for designing groundwater remedies involving iron PRBs and natural attenuation processes.

The PRB probabilistic model 85-percentile VOC effluent concentration levels were used to determine the minimum iron PRB average-effective thickness required to bring VOC concentrations to below MCLs. The required PRB thickness for four (4) design cases varied from a minimum of 3 inches to a maximum 4-1/2 inches. Input data sensitivity analysis was performed to quantify the impact of parameters variability on overall system performance as shown on Figure 1, and thus ranked each parameter by sensitivity. Probabilistic methods can accommodate variability in parameter data and are ideally suited for system design such as an iron permeable reactive barrier. The probabilistic method enables quantification of the degree of confidence that contaminant effluent concentrations are not exceeded for the various design cases.

Quality control verification methods are especially important for PRB construction to verify in situ placed geometry and the PRB's minimal impact on the groundwater flow regimes. Direct in situ sampling of an undisturbed iron PRB can be difficult at depth and/or in flowing ground conditions. Driven probe techniques utilizing electrical resistivity and magnetometer are proposed as viable methods to determine PRB geometry, and hydraulic pulse interference tests are proposed to quantify the hydraulic impact of the PRB on groundwater flow regimes.

CONCLUSIONS

The design methodology for the PRB incorporated a probabilistic multi-specie VOC degradation model for degradation within the PRB and a probabilistic fate and transport model for VOC natural attenuation downgradient of the PRB. The PRB probabilistic model 85-percentile VOC effluent concentration levels were used to determine the minimum iron PRB average-effective thickness required to bring VOC concentrations to below MCLs. The PRB probabilistic design model allows for variability of site formation hydraulic conductivity, groundwater flow gradients, VOCs concentration levels, VOC degradation half-lives and degradation pathways from iron column test data, PRB installed thickness and iron PRB porosity.

REFERENCES

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