# PROBABALISTIC DESIGN OF A COMBINED PERMEABLE BARRIER AND NATURAL BIODEGRADATION REMEDY

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Probabilistic design models are useful and effective tools for optimizing the design of permeable Reactive Barriers (PRBs). They allow the design engineer to use all of the available data on the site conditions and treatability testing results to develop the full distribution of input conditions and anticipated performance with an associated probability distribution. The output of this analysis can then be used to select a design thickness of iron at a given confidence level, typically in the 85 to 95 percent range. This approach provides much more efficient resource utilization when compared with the more traditional approach of using only worst case input conditions to calculate a design thickness, or by applying arbitrary safety factors.

A probabilistic model was used to design a combined PRB and natural biodegradation remedy for a Carbon Tetrachloride (CT) plume at a former manufacturing site. CT degrades rapidly in the presence of Zero Valent Iron (ZVI) to non-chlorinated end products (methane and carbon dioxide), with partial conversion to Trichloromethane (TCM) and Dichloromethane (DCM). In order to measure site-specific reaction rates and daughter product yields, laboratory column studies were conducted using ZVI and groundwater from the CT plume at the site. The half-life for CT was found to be 0.2 hours, or 12 minutes.

Natural biodegradation was evaluated and found to be an effective means of degrading the generated DCM daughter product, thereby achieving complete dechlorination of the parent CT to non-chlorinated end products prior to reaching the compliance point. CT, TCM, and DCM are all known to naturally biodegrade under reducing conditions. Biodegradation and ZVI treatment are very compatible treatment processes. In fact, ZVI treatment may make the groundwater conditions more favorable for downgradient biodegradation by creating more reduced conditions and generating hydrogen. A treatment train of a ZVI permeable barrier followed by natural anaerobic biodegradation can be an effective remediation approach for chlorinated solvent plumes. The process is shown conceptually in Figure 1.

The primary basis for PRB design is to provide adequate residence time in the PRB for

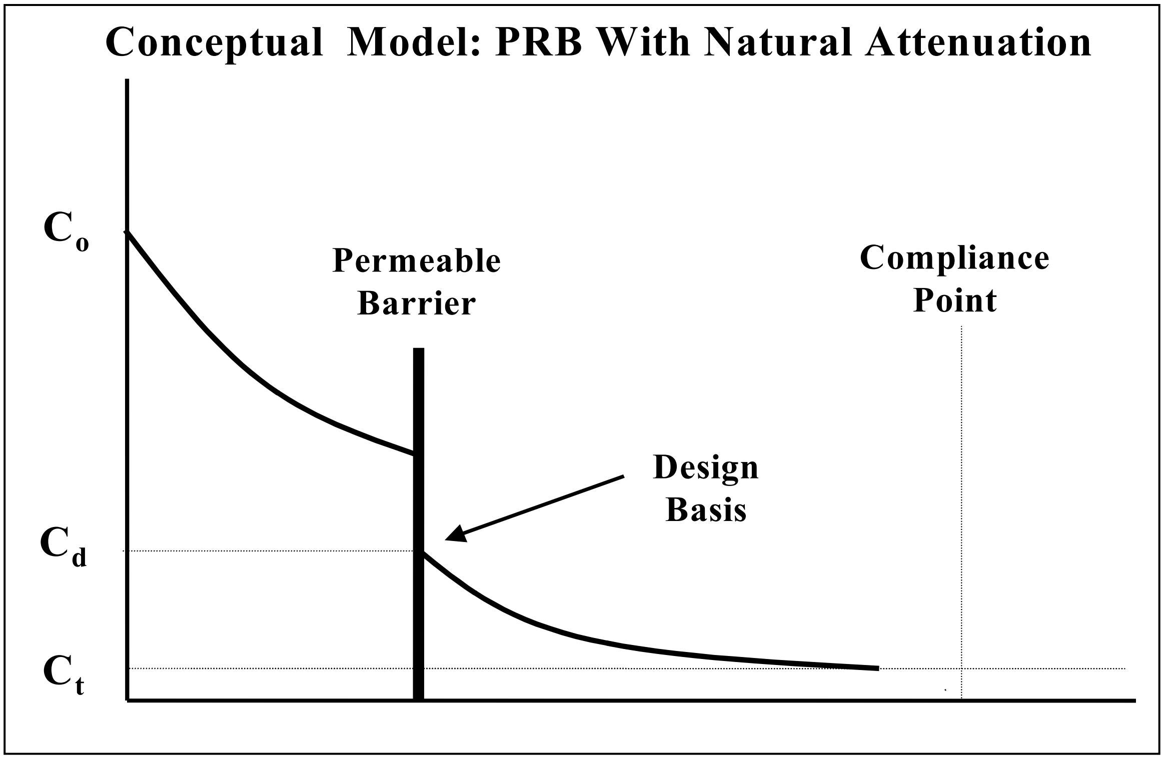
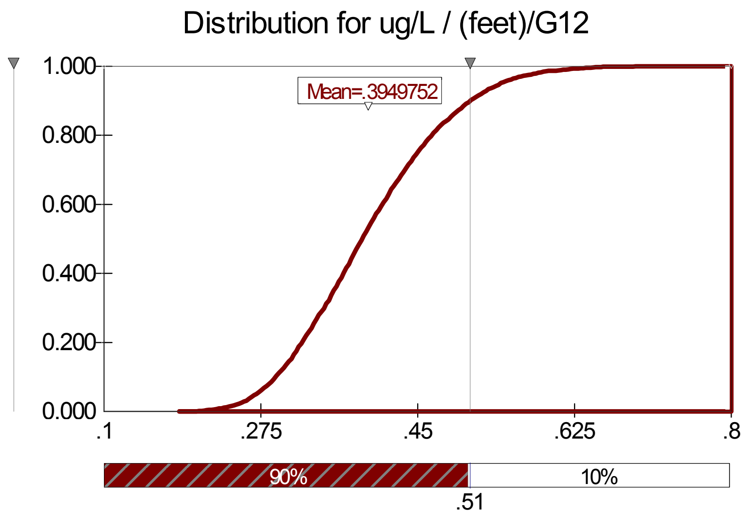



**FIGURE 1**
**PRB VOC Degradation Model coupled with Natural Attenuation**

the ZVI driven degradation reactions to proceed to the desired end-points. Residence time is a function of reaction rates (as determined by laboratory studies), Influent contaminant concentrations, groundwater temperature, and desired contaminant concentration end-points. Residence time is then translated into a design thickness of the PRB using the groundwater velocity, and the permeability/porosity of the iron in the PRB. These parameters were used as input to a probabilistic design model, which served as the basis for predicting the performance of a 6-inch thick PRB at the subject Site.

The first step in the probabilistic design analysis was to input the range of values for each design parameter. The ranges were based on historical and measured data from the Site. A distribution of concentrations of CT was used as input to the model, with a most probable concentration of 80 ppm. A Monte Carlo analysis was then conducted using 5000 iterations resulting in predicted output concentrations of CT, TCM, and DCM. As an example, Figure 2 below shows the output confidence level of a Monte Carlo analysis for degrading TCM. Using 6 inches of ZVI, there is a 90% confidence level that the effluent TCM concentration will be 100 ppb or less at the specified input concentrations of carbon tetrachloride and TCM.




Percent Confidence Level (1.0 = 100%)

Barrier Thickness (feet)

**FIGURE 2**
**Chloroform Generation and Degradation**

The output of the design analysis for the 6-inch thick PRB was used as input to the natural biodegradation analysis. These input values were 0 ppb of CT, 100 ppb of TCM, and 8 ppm of DCM. The purpose of the analysis was to determine whether there is sufficient distance downgradient of the PRB to achieve the remedial objectives for these two compounds prior to reaching the compliance point. At the subject site, the PRB was placed approximately 1,000 feet upgradient of the compliance point, a surface water boundary. With an average groundwater velocity of approximately 0.5 feet per day, the available residence time for biodegradation is 2,000 days, or approximately 5.5 years.

With a biodegradation half -life of 10 days and a groundwater velocity of 0.5 feet per day, 8 ppm of DCM will be reduced to less than 1 ppb in less than 75 feet downgradient of the PRB. Approximately 13 half-lives are required, and 200 are available. A similar analysis for TCM with a half-life of 100 days shows that 100 ppb of TCM will be degraded to below 1 ppb within 350 feet downgradient of the PRB. Approximately 7 half-lives are required and 20 are available.