HRC TECHNICAL BULLETIN #2.5.1

Plume Area Treatment Example

HRC injection grids are commonly employed at project sites where a localized plume of chlorinated solvent contamination exists. HRC injection grids are often applied to affect a very cost-effective remediation. The design process for this treatment strategy is described below for a hypothetical site. After the example, a description of the various spreadsheet input parameters is provided for reference.

Step 1: Gather Relevant Site Assessment Data

As with any remediation design, the first step is to gather the relevant site assessment data. For example, consider the following site:

Lithologic data: Groundwater is located 10 feet below the ground surface (bgs) and extends to a depth of 40 feet bgs at which point a clay aquitard is encountered. Aquifer sediments consist primarily of silty sands.

Contaminant concentrations: PCE concentration ranges from 0.1 to 5 mg/L. Daughter products of the biological degradation of PCE are identified at the following concentrations: TCE at 0.5 mg/L and cis-1,2-DCE at 0.5 mg/L.

Extent of impacted groundwater:

The aerial extent of the contaminant plume is estimated to be 50 feet wide by 100 feet long.

Most groundwater monitoring wells contain screen intervals that extend to a depth of 20 feet bgs. Vertical profiling of the contaminants is accomplished by (1) installing several groundwater wells with screened intervals located from 25 to 30 feet bgs and (2) by collecting groundwater samples using direct push equipment. This results in the conclusion that the contaminants are limited to the upper 15 feet of the aquifer.

Aquifer redox conditions: ORP = 100 mV, DO = 2 mg/L, nitrate = 1 mg/L, dissolved iron = 10 mg/L, sulfate = 50 mg/L

Additional aquifer parameters: The following parameters were collected through soil and groundwater investigations or estimated or calculated using industry standard procedures: fraction of organic carbon (0.005), porosity (0.3), hydraulic gradient (0.005 ft/ft), hydraulic conductivity (10 ft/day or 3.5x10-3 cm/sec), groundwater velocity (60 ft/yr).

Step 2: Evaluate Site Data and Specify HRC Grid Design and Cost

The next step is to determine the scope of the remediation. After evaluating health risks and groundwater quality thresholds, the designer specifies a cleanup goal and the extent of the contaminant plume requiring remediation. For this example, assume that the following decisions are made concerning the remediation design:

Aerial and vertical extent of aquifer requiring remediation: 50 feet x 100 feet x 15 feet

HRC TECHNICAL BULLETIN H-2.5.1 – pg. 2

Conservative estimate of contaminant concentrations to be bioremediated: 5 mg/L PCE, 0.5 mg/L TCE, and 0.5 mg/L cis-1,2-DCE

The presence of daughter products from the reductive dechlorination of PCE indicates that the biodegradation of PCE is occurring to a limited extent. Geochemical parameters (ORP, DO, etc.) indicate that the aquifer redox conditions are not yet in the optimum range for the reductive dechlorination of chlorinated hydrocarbons. Furthermore, there is no apparent electron donor (or hydrogen source) to stimulate further dechlorination. The remediation designer decides that HRC can be used to provide the aquifer with a consistent low level of hydrogen accelerating the reductive dechlorination of PCE and its daughter products.

The quantity of HRC needed to fuel the reductive dechlorination process is estimated using the site assessment data and general design guidelines. The HRC grid design process is simplified by using the HRC Grid Design worksheet found on the HRC Application Software (available from Regenesis) and consists of specifying the following design variables:

Site information: Plume dimensions, aquifer transport parameters, and contaminant and CEA concentrations are entered into the worksheet.

Demand factors: A microbial demand factor of 3x is used, and an additional demand factor of 3x is chosen since the entire source of the contaminant plume is targeted for remediation with one application of HRC.

HRC delivery point spacing: A delivery point spacing of 10 feet on center is selected to provide a reasonable distribution of HRC into the contaminant plume. This results in an HRC grid of 10 rows of 5 points per row, for a total of 50 delivery points.

HRC injection amounts: The contaminant and competing electron acceptor concentrations, adsorbed phase concentrations, and demand factors are used to estimate the required amount of hydrogen and corresponding HRC required for the reductive dechlorination reactions. For a 10 feet-on-center spacing (and 50 total injection points as determined above), a vertical HRC application rate of 6.8 lbs/ft is calculated by the software. Therefore, a total of 5,107 pounds of HRC are required (50 points with 15 feet of injection per point at 6.8 pounds of HRC per vertical foot).

Cost estimate: The HRC material cost for this example is $6/lb for a total of approximately $30,640. Costs of HRC product, shipping and applicable taxes vary from site to site and should be requested from Regenesis' sales or technical support staff if a detailed cost estimate is needed. HRC installation costs can be estimated using a daily rate for the injection subcontractor and an estimate of the production rate for the site. For this example, it is assumed that two injection points can be completed per hour and that a Geoprobe rig costs $2,000 per day and is mobilized for $1,000. The installation cost for 50 injection points to a depth of 25 feet is then $9,000, resulting in a total installation and HRC material cost of approximately $40,700.

To summarize, the following issues should be considered during the HRC grid design and cost estimation process:

Injection point spacing typically ranges from 5 to 15 feet-on-center, and its specification depends on groundwater velocity, sediment permeability, required HRC injection amounts, and HRC grid size.

The HRC injection rate for each point typically ranges from 4 to 10 lb/ft, and its specification depends on the contaminant concentrations, competing electron acceptor concentrations,

HRC TECHNICAL BULLETIN H-2.5.1 – pg. 3

competing microbial demand, and soil type. It should be noted that using fewer points and higher doses might not provide sufficient distribution of HRC and lactic acid throughout the contaminant plume.

For larger plumes and/or large ranges of contaminant concentrations, the HRC dose rate should be adjusted as appropriate (i.e., the plume can be divided into high-, medium-, and low-contaminant concentration areas, each with a specific HRC dose rate).

- The need for reapplication of HRC will depend on achievable biodegradation rates, remedial goals for the site, proximity of downgradient receptors, and other technical/regulatory issues. Some sites will require only one application of HRC, while others may require multiple reapplications (the reapplications typically will be done at lower HRC doses and in a smaller grid area).

Input and Output Parameters for HRC Applications Software

1) General Information on Software Use

User input parameters are shown in blue, whereas cells containing the results of calculations are shown in black. Red warnings or guiding comments may be generated in response to the spreadsheet calculations. Dialog boxes and point and click buttons are available to assist with data entry and to navigate the software.

2) Basic Site Characteristics

Basic site characteristic parameters are needed to specify the physical site characteristics. The width and depth of the contaminant plume refer to the planned treatment area, which can vary depending on remedial goals and cleanup strategy.

Thickness of the Contaminated Saturated Zone specifies the vertical thickness across which HRC will be delivered. The vertical thickness is dictated by the estimated thickness of the contaminant plume. For instance, if a site has a contaminant plume spanning the saturated zone above an aquitard, then the design should treat the aquifer down to the aquitard. If the contaminant plume is limited to a localized depth interval or lithologic layer, then HRC injection can be limited to the contaminated depth interval.

The HRC material cost is proportional to the thickness specification. Therefore, it is important to determine the vertical contaminant distribution as accurately as possible. If only moderate concentrations of contaminant are present, and no vertical profile of the plume has been done, Regenesis suggests that the user assume a thickness of approximately 20 feet. Porosity refers to the total porosity of the aquifer soil matrix. Using the above input parameters, the software will calculate the treatment zone pore volume.

Next, information regarding aquifer transport properties are requested. The hydraulic gradient and conductivity are used to calculate the groundwater seepage velocity, which can be used to select delivery point spacing and evaluate flow dynamics within the grid.

3) Dissolved-phase Groundwater Concentrations

Under this category of input parameters, representative contaminant concentrations are specified for the area where HRC will be delivered. Specifically, dissolved-phase concentrations that are determined by groundwater well sampling and analysis are entered here. While it is important to consider the most recent data available, the input values should represent the concentration that the user judges to be indicative of actual subsurface conditions over the course of an entire hydrogeologic cycle.

Regenesis has included input spaces for the most commonly encountered chlorinated solvents;

however, HRC will stimulate the degradation of a myriad of pollutants. If the contaminant the user is concerned with is not listed for input, please contact Regenesis directly. We will be glad to assist in determining the amount of HRC required to treat other less common contaminants.

4) Sorbed Phase Contaminant Mass

For HRC grid designs, there is usually a multiple of the total dissolved contaminant mass that is bound to the saturated soil zone matrix. This is called hydrophobically sorbed contamination and can be visualized as a thin layer of contaminant that is retained by clean aquifer materials when they come into contact with a dissolved contaminant flow. The mass of contaminant sorbed to the aquifer matrix is a function of the bulk density of the aquifer matrix, the fraction of organic carbon in the matrix (foc), and the contaminant-partitioning coefficient (Koc). An estimate of the mass of sorbed contamination is calculated in this section by entering the factors mentioned above. Input values for the soil, the bulk density, and the fraction of organic carbon (foc) can be measured or estimated based on soil type. The Koc value can be obtained for each contaminant from any number of published references.

5) Competing Electron Acceptor Concentrations

The concentrations of competing electron acceptors (CEAs) such as dissolved oxygen, nitrate, ferric iron, and sulfate have an effect on the amount of HRC required for enhancing in-situ bioremediation. Hydrogen from the HRC is used to reduce these CEAs to create redox conditions that are conducive to reductive dechlorination processes. As a result, the CEA demand for hydrogen (and consequently HRC) must be considered in the specification of the amount of HRC required for a project. Groundwater data indicating the actual site values for these parameters are important in determining an accurate final design for HRC application. However, in the absence of these data, reasonable estimates of these values can be made to generate a preliminary design and cost estimate.

6) Microbial Demand Factor

In addition to contaminant and CEA demand for HRC, subsurface microbes will use some of the lactic acid as a source of energy or structural carbon. Therefore, in designing an HRC application, these competing microbial processes must be taken into account. Regenesis' experience indicates that a value of 3 suffices under most conditions. However, if site-specific laboratory microcosm data are available, the designer can input the appropriate value directly.

7) Additional Demand Factor

Additional Demand Factor is used to account for uncertainty about the potential sinks for electron donor. This factor can be thought of as a contingency or safety factor, which is used to account for the many uncertainties inherent in a subsurface investigation and in situ remediation project. Potential sources of additional HRC demand include higher than expected contaminant mass (in the form of residual phase DNAPL and/or high concentration hot spots), microbial demand in excess of the estimated 3x, and uncertainty about the quantity of HRC required for the reduction of iron and manganese. The simple measurement of the concentrations of these competing electron acceptors in groundwater samples does not give an accurate representation of the iron and manganese reduction demand since these species may be present either as colloids or attached to the soil matrix. Regenesis recommends an additional demand factor of 2 to 3 for a first application at a site.

8) Life Span for One Application (for barrier designs)

For HRC barrier designs, the life span for one application should be input in this field.

This value is used with the groundwater seepage velocity to estimate the flow of contaminant mass into the barrier during this period of time.

9) HRC Delivery Point Spacing and HRC Dosing Rate

For grid designs, the recommended spacing for HRC delivery points ranges from 5 feet-on-center to 15 feet-on-center. Spacing is a function of soil type, groundwater velocity, and necessary HRC dosing. Generally, the lower the hydraulic conductivity of the soil matrix, the closer the spacing. For sites with silts and clay, delivery point spacing should be 5 to 8 feet-on-center, while a site with sands and gravels may have a spacing up to 15 feet-on-center. The Delivery Point Spacing section of the Grid Design worksheet allows the designer to calculate the required number of points and HRC dose rate for a given plume size and spacing.

For barrier designs, a series of staggered HRC injection point rows are typically constructed. The effective spacing of delivery points perpendicular to the groundwater flow should be no more than 10 feet-on-center. The Delivery Point Spacing section of the Barrier Design worksheet allows the designer to estimate the required number of points and HRC dose rate for a given barrier length and contaminant flow rate.

10) Proposed HRC Grid Specifications

In this section of the worksheet, the designer may adjust the total number of injection points and the HRC dosing rate or leave it as calculated. The software will then calculate the cost of HRC material and estimate the cost of shipping and taxes for the given scope of the project (i.e., number of points, treatment thickness, and HRC dosing rate).

11) HRC Installation Cost Estimate and Total Project Cost

Although Regenesis does not perform installation services, our experience on many applications has given us an understanding of the costs associated with installing the HRC. This section offers the designer an opportunity to estimate how much the HRC grid or barrier application will cost. The suggested input parameters required are based on Regenesis' experience. The result of this section is an estimated subcontractor installation cost. This estimate should be adjusted based on local contractor costs. The Total Project Cost provided represents the sum of the HRC Installation Cost Estimate and the HRC Material Costs. It does not include the costs associated with groundwater monitoring, reporting, or consulting oversight.