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Substrate Comparison of Three Permeable Reactive Barriers for Protection of a Building Sump from Perchlorate Impacts

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ABSTRACT: An in situ anaerobic remediation system was designed and installed to remediate perchlorate-contaminated groundwater that was identified at an industrial facility in 2008. The groundwater surrounding the building was determined to be hydraulically controlled by a sump located in a portion of the building. A full-scale remediation system was designed and installed to use the sump as a focal point for the extraction and recirculation of perchlorate contaminated groundwater. The extracted groundwater is recirculated into a series of active permeable reactive infiltration trenches for treatment. A total of 550 feet (167.6 m) of infiltration trench were installed. Each trench was positioned to allow for a majority of the recirculated water to be recaptured by the groundwater sump allowing for the treatment of the source area soils and create a recirculation loop. Different supplemental carbon donor substrates were evaluated and selected for each of the three trenches based on the anticipated travel time for groundwater to migrate from the infiltration trench back to the extraction point. It is anticipated that the use of different substrates based on their physical properties will allow for the most effective treatment zone capable of reducing perchlorate without the unwanted development of excess biomass that can develop in in situ bioremediation systems.

INTRODUCTION

During a RCRA Facility investigation, perchlorate contamination was identified in the shallow soils and the shallow groundwater aquifer in close proximity to a building within an industrial facility. Groundwater samples collected from the area indicated perchlorate concentrations in groundwater ranging from <0.004 mg/L to 22.4 mg/L. Groundwater elevation measurement collected from monitoring wells surrounding the building verified that groundwater in the vicinity of the building was hydraulically controlled by the groundwater sump that was located approximately 23 feet (7.0 m) below ground surface in the building. The sump was in continuous use to keep the basement of the building dry. Flow measurements from the sump indicated that the groundwater sump pumped at an average rate of 24 gallons per minute. This pumping had created a localized cone of depression in the area surrounding that building. Figure 1 depicts the locations of the groundwater sump and the groundwater cone of depression that has been created by the sump. Based on the elevated perchlorate results observed in the groundwater, an in situ bioremediation system was designed to remediate the observed perchlorate groundwater concentrations.

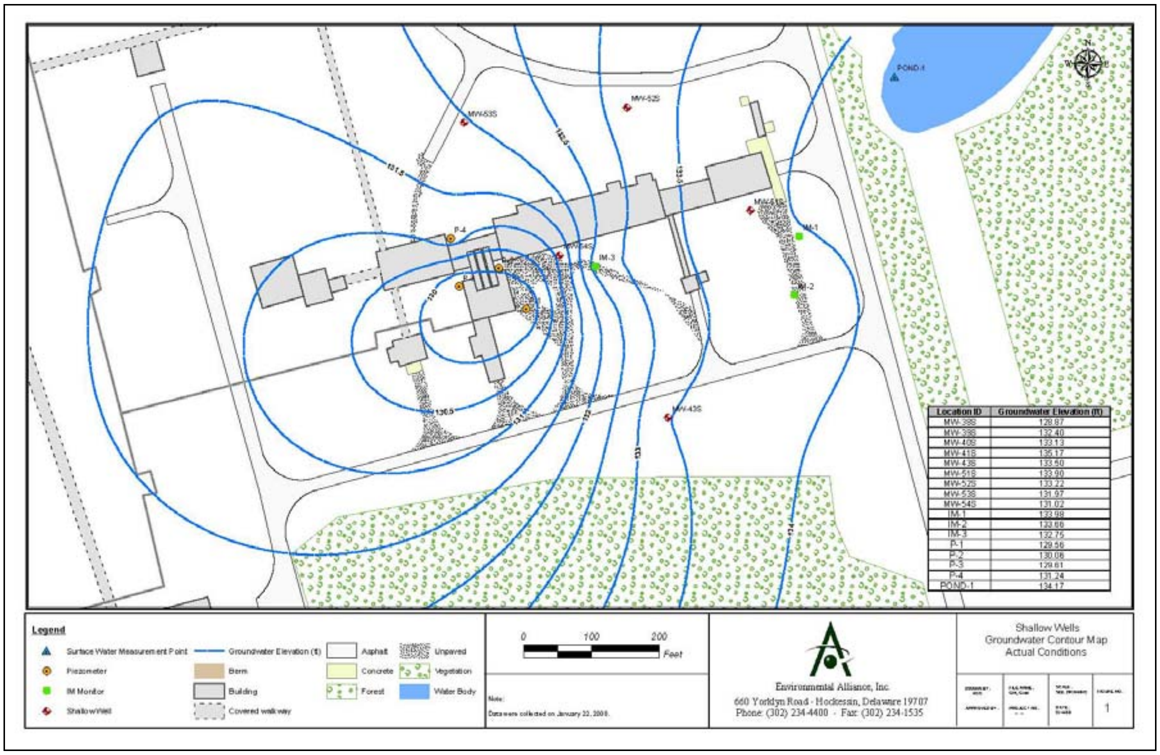

FIGURE 1. Shallow wells groundwater contour map actual conditions.

GEOLOGICAL SETTING

Generally, the area of interest consists of a fine-grained sequence present from ground surface down to about 15 feet (4.6 m). Typically, a layer of silt to very fine-grained sand up to 5 feet (1.5 m) thick is present at the surface and is underlain by clay or clayey sand. Fine-grained sand with little or no clay is present below the clayey sand. Gravel bearing sediments underlie the fine-grained units, starting at a depth of about 15 feet (4.6 m). The gravel contains fine pebbles to cobbles, all typically rounded. The matrix varies with varying amounts of sand, silt, and clay. Groundwater is generally encountered between 7 and 17 feet (2.1-5.2 m) below ground surface with seasonal fluctuation of 10 feet (3.0 m).

TREATMENT SYSTEM DESIGN

As an interim measure for the RFI, a series of in situ active recirculation trenches were selected as the remedial strategy to provide for the discharge point for the water pumped from the building sump, reduce and treat the recirculated water for perchlorate contamination and ultimately, to remediate the source area. A groundwater model using MODFLOW™ was developed to assist in the design of the interim measure to determine the appropriate length and orientation of the trenches to allow for the infiltration of the discharge water and assist in trench design to minimize the possibility of groundwater to rise to the level of ground surface under pumping conditions.

The groundwater model was performed to provide a quantitative method for evaluating various design scenarios for the groundwater recirculation trenches to ensure proper placement, length, orientation and distribution of flow. In addition, the groundwater model was used to simulate groundwater flow path, potential water table mounding, and projected flow lines from various trench designs and configurations including depth and orientation of the trenches. The groundwater model incorporated specific data collected during the investigation phase including: site specific geology, slug test data, and geotechnical laboratory testing results. The model indicated that a series of three trenches would be capable of recirculating an anticipated flow of 24 gallons per minute from the sump. Figure 2 depicts the output from the groundwater model indicating the simulated flow paths of groundwater under pumping condition in which the sump discharge water is directed to the interim measure trenches.

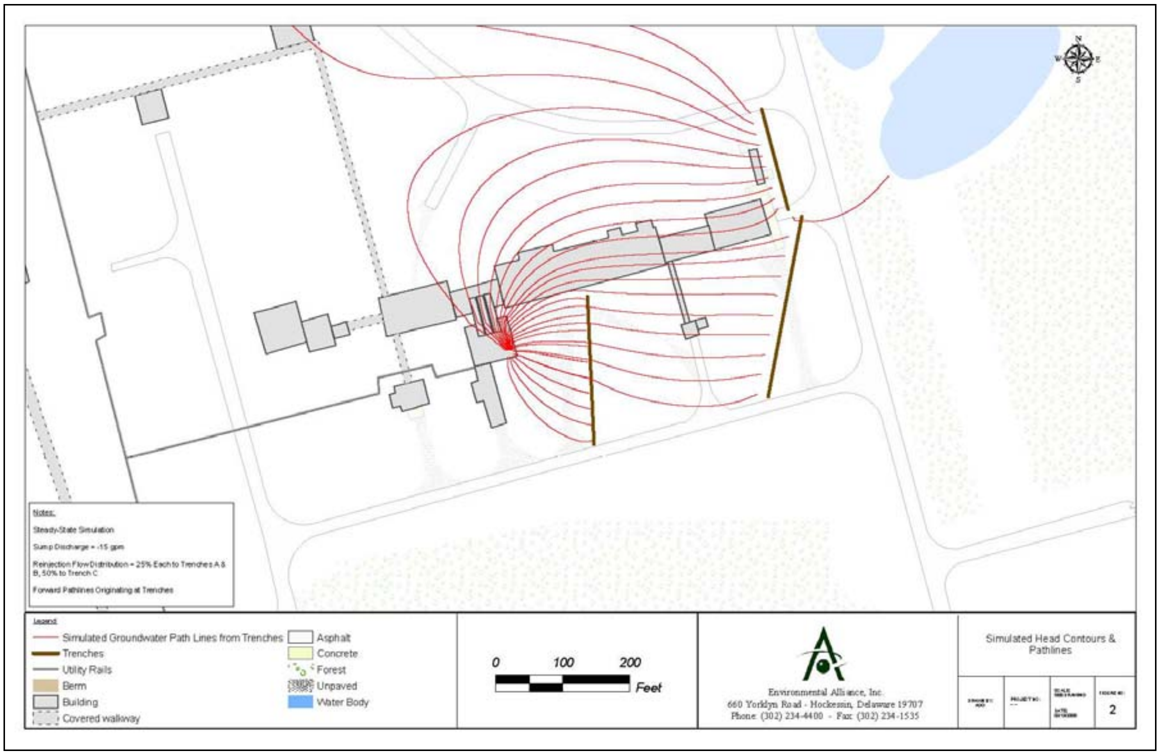

FIGURE 2. **Simulated head contours and pathlines.**

The flow paths generated from the groundwater model indicate that a majority of the groundwater re-injected would be recaptured within the cone of depression created by the sump and be recirculated within the treatment zone to create a recirculation loop within the remediation zone.

In addition to confirming the optimum orientation of the trench system, the groundwater model results indicated that each trench must be installed to a depth that penetrates the more permeable gravel zone located 15–20 feet (4.6–6.1 m) below ground surface.

Based on the results of the groundwater model, three trenches were designed and positioned in the field according to the groundwater model recommendations. Minor adjustments were made in the field to account for underground utilities and site specific conditions. Each trench was installed to a depth of between 17 and 20 feet (5.2–6.1 m) below ground surface to contact the more permeable gravel zone. Upon excavating to a depth in which the gravel zone was encountered (typically 15–20 feet bgs), the trench was backfilled with a 50/50 mixture of hardwood mulch and pea gravel to 10 feet (3.0 m) below ground surface. Hardwood mulch was added to provide a long lasting carbon donor substrate to encourage the development and to maintain anaerobic conditions within the treatment zone. The pea gravel was added to minimize the potential for the hardwood mulch to compact and limit infiltration rates within the trench. Above the hardwood mulch/pea gravel layer, a three foot thick layer of pea gravel was installed with a four inch pre-wrapped perforated HDPE pipe in the middle of the pea gravel. The four-inch perforated pipe will act as the infiltration pipe for the recirculated water to be re-injected into the infiltration trench. The four-inch pipe is attached to a 3-inch water supply line originating from the groundwater sump. Immediately above the pea-gravel a layer of filter fabric was installed to prevent fine sediments from migrating into the trench and limiting infiltration rates of the trench. Above the filter fabric native soil was used to backfill the excavation.

During trench construction, monitoring points were installed within the trench. These monitoring points were installed to monitor groundwater elevations within the trench to determine if the re-injected water was being equally distributed across the trench and to evaluate groundwater geochemical conditions within the trench.

SUPPLEMENTAL CARBON DONOR SUBSTRATE ADDITIONS

Based on the groundwater-flow paths provided in the groundwater model for each trench and the volume of water that was to be recirculated, two different supplemental carbon donor substrates were selected to augment the hardwood mulch. The different supplemental electron donor substrates were selected based on the physical properties of each substrate. The substrates were also selected to limit the potential for excess biofilm to develop and allow for the substrate to be persistent in the groundwater throughout the recirculation loop that has been created. See Figure 1 for the designations of each trench and locations of the recirculation point (sump).

No supplemental carbon donor substrates were made to Trench A. Trench A will only utilize the hardwood mulch that was installed during construction of the trench. This trench is located the closest to the recirculation point and therefore has the shortest travel time. With a relatively short groundwater recirculation time, supplemental electron donor substrates might encourage the development of unwanted biomass that is can be created within an in situ remediation system. The development of the biomass could potentially reduce the conductivity of the groundwater aquifer and limit infiltration rates.

Calcium magnesium acetate (CMA) was selected for Trench B. CMA is readily soluble within groundwater and as such will readily dissociate within the subsurface environment. The solubility properties of CMA will make it a very fast acting and short lived electron donor source, properties that are beneficial for the operation of Trench B. Trench B is located up groundwater gradient of Trench A. It is anticipated that the CMA injected into Trench B will be an effective electron donor source for the area immediately surrounding Trench B, but will have generally dissociated by the time the groundwater has migrated to the area of Trench A. This result was desired to prevent the possibility for an excessively anaerobic groundwater condition in the area of Trench A. If excessively anaerobic water were to infiltrate into Trench A and eventually into the recirculation point, there could be an increased potential for excess biomass to develop which would in turn hinder infiltration rates.

Trench C utilizes the vegetable oil based product Newman Zones Non-Ionic Buffered Solution. As simulated by the groundwater model, water re-injected into Trench C will have the greatest travel time before being recaptured by the sump or migrating out of the treatment zone. As a result of this extended travel time and the potential for some of the groundwater not to be recaptured, a long lasting slow releasing substrate was desired to extend the treatment zone as far down groundwater gradient as possible. The long lasting slow releasing substrate will allow for the treatment zone to extend the greatest distance from Trench C and specifically to maximize the possibility of extending under the building foot print.

As described above, the use of different carbon-donor substrates is a critical portion of the remedial strategy for this treatment design. The substrates were specifically selected based on the travel time of the recirculated groundwater to maximize the effectiveness of each substrate while at the same time minimizing the potential for the development of excess biomass.

RESULTS AND DISCUSSION

The monitoring of the remedial action consists of collecting water samples and geochemical parameters from the shallow groundwater aquifer down gradient of the infiltration trenches on a monthly basis. The monthly sampling consisted of analysis for perchlorate and monitoring specific geochemical parameters (DO, ferrous iron, ORP) that is critical to the remedial process.

Since the infiltration trenches became operational, the down gradient-monitoring points have been observed to develop conditions that are favorable for perchlorate reduction. Dissolved oxygen measurements are generally below 0.5 mg/L. ORP measurements are generally observed to be decreasing with many down gradient monitoring locations demonstrating negative ORP measurements. Additionally, ferrous iron detections within the down gradient monitoring wells are observed to be increasing with detections as high as 8 mg/L.

Groundwater geochemical conditions slightly up-gradient of the trench are also becoming more favorable for perchlorate reduction. A review of the groundwater elevation measurements collected within the remedial area indicates that as groundwater mounds within the immediate area of each infiltration trench there is a potential for groundwater to migrate up-gradient for a short distance within the area of the groundwater mounding effect.

The data collected thus far indicate that each trench is capable of creating sufficient conditions that will facilitate the in situ anaerobic degradation of perchlorate. Each trench has in a short period of time (<6 months) created a large treatment zone capable of perchlorate reduction. Numerous monitoring locations throughout the treatment zone are observed to exhibit decreasing perchlorate concentrations since the interim measure became operational. The rates at which anaerobic conditions developed within each trench was observed to be relatively similar when compared to the other trenches indicating that the hardwood mulch is very effective at facilitating the development of a reducing environment.

Continued monitoring will be conducted to determine if the selected substrates enhance the rate of perchlorate reduction within the treatment area when compared to the other two trenches. Each trench will be evaluated to determine how long the hardwood mulch can function as an effective electron donor for the remedial process.

Geochemical data indicate that the substrate injected into Trench B and Trench C is migrating with groundwater as it is recirculated into each of the trenches. The groundwater geochemical parameters indicate that the treatment zone is being extended and will encompass the entire area between the infiltration trenches and the extraction point. So far no indication of the development of excess biomass has been observed in any of the trenches or monitoring points.

CONCLUSIONS

Based on the data collected to date, the use of different supplemental electron donor substrates appears to be effective at creating suitable conditions for anaerobic perchlorate degradation while at the same time limiting the development of excess biomass that could hinder the remediation process.

The results indicate that the physical properties of a substrate should be considered and evaluated to determine the most effective substrate while at the same time working to minimize potentially high maintenance costs associated with the development of excess biomass within the remediation system.

The following additional items are recommended to further evaluate the effectiveness of the different substrates as it relates to the success of the remedial action.

- Additional biological sampling including anaerobic plate count analysis and qPCR analysis to determine the overall health and extent of the microbial community responsible for perchlorate reduction.
- Use the data from the biological sampling in conjunction with the analytical data to determine the rate of perchlorate degradation per day for each of the substrates and determine optimum substrate concentrations to maximize perchlorate reduction.

These additional items will help to maximize the effectiveness of the interim measure and will supplement the ongoing program that is designed to monitor the effectiveness of the two substrates and prevent the development of excess biomass.