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Shallow Infiltration Trenches to Remediate a Chlorinated Solvent/Perchlorate Plume

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ABSTRACT: A field-scale pilot test utilizing infiltration trenches in conjunction with a shallow groundwater recirculation system was initiated at an industrial facility with shallow groundwater and soil impacted with chlorinated solvents and perchlorate. The pilot tests were designed to determine if shallow (less than 3 meters) aerobic subsurface conditions could be manipulated to create an in situ anaerobic bioremediation system capable of reducing both perchlorate and chlorinated solvents to innocuous end products. Eight shallow trenches were installed from 2002 to 2004. The trenches were backfilled with a gravel/mulch mix and incorporate a horizontal injection line for the introduction of supplemental substrates to generate a treatment zone encompassing approximately 6.75 acres (27,316 m^2). The most downgradient monitoring well of the trench system indicates 99.99% reductions in perchlorate and almost 90% reductions in chlorinated solvents. A greater than 80% reduction in the contaminants have also been observed in an adjacent stream impacted by groundwater discharge to the surface. The positive results of the trench pilot test indicates that this type of system is feasible for full-scale implementation at the Facility to treat chlorinated solvent and perchlorate impacted soil and groundwater to risk-based levels that are protective of human health and the environment.

INTRODUCTION

In 2001, a sampling program of surface water, sediment, shallow groundwater, and deep (bedrock) groundwater was initiated at select locations (some monitored as part of ongoing corrective actions) to determine the presence of perchlorate at the Facility. Perchlorate, primarily as ammonium perchlorate (AP), had been used as an ingredient in solid rocket propellant manufacturing operations at the Facility since 1960. The results of the initial sampling program reported the presence of perchlorate in shallow and deep groundwater, and in surface water at several stream locations. The site has been operating under a RCRA consent order since the early 1990's with documented contamination from chlorinated solvents also in the surface, shallow and deep groundwater systems.

Phased shallow groundwater pilot study activities were initiated in August 2002 and again in July 2004 adjacent to a main contaminant source area for shallow groundwater and surface water. These pilot study activities were initiated to assist in determining appropriate remedial actions to address both the recently detected perchlorate and historically reported VOC impacts where they coincide in shallow and deep groundwater.

Topographically, the facility is characterized by approximately 60-feet (18.3 m) of relief, ranging in elevation from 340-feet (103.6 m) above mean sea level at the western boundary to 280-feet (85.3 m) above mean level (amsl) at the southeastern boundary. Most of the onsite streams reflect a dendritic drainage pattern with principal directions of flow to the south and southeast.

In general, the facility consists of unconsolidated sediments overlying bedrock of the Piedmont Physiographic Province. The unconsolidated sediments identified from literature reviews, soil borings, and well installations conducted at the facility consist of sandy-silty clay to sandy silt with clay lenses. These soils have been characterized to have moderate to poor drainage. The thickness of the unconsolidated sediments encountered at the facility range from 1.5 to 19.5-feet (0.46 to 5.9 m) overlying bedrock. Shallow groundwater in the infiltration trench area is perched upon and collects in depressions in the relatively impermeable diabase bedrock surface.

Groundwater flow in the trench area appears to be controlled by surface drainage to the east, namely the stream located immediately to the east of the trench area and its confluence with the stream running along the southern portion of the facility and pinnacled bedrock on the western boundary of the treatment area. Based on historical water-level monitoring and field flow observations, these streams are believed to act as partial divides for the shallow groundwater in this area, gaining flow from groundwater discharge during the wetter months of the year (December through May). An additional factor influencing groundwater flow and contaminant transport in this area is the presence of the subsurface utilities such as sanitary sewers. The gravel backfill material surrounding these sanitary sewers is substantially more permeable than the native soils, therefore potentially act as a preferential pathway for transport of VOCs and perchlorate.

METHODS AND MATERIALS

The infiltration trench (IT) pilot study system operation was initiated in September 2002 with the installation of 3 trenches located south of a main contaminant source area. This southern IT system includes a recirculation well, located between 2 of the ITs to increase the length of the treatment zone parallel to groundwater flow. Five additional ITs, as an addition to the southern IT system, were installed July and August of 2004 and are located east and north of the main source area. A recirculation system is also included as part of the northern IT system. The current operational IT system consisting of the eight ITs and two recirculation systems, with a depth of 5 to 15-feet (1.5 to 4.6 m) overlying the diabase bedrock. The trench system is designed to treat shallow groundwater in an area of approximately 6.75 acres (27,316 m^2) surrounding the main source area.

The ITs were installed perpendicular to groundwater flow and transect the shallow groundwater system bounded by the impermeable diabase pinnacled at the surface on the western boundary and the surface stream on the east.

Each IT is constructed with a 4-inch (10.2 cm) diameter corrugated black poly leach pipe installed near the base of the trench to facilitate substrate injections. The leach pipe is connected at the surface to a one-inch (2.5 cm) diameter injection point. The leach pipe is also surrounded by up to 4 feet (1.2 m) of a gravel/mulch mix to prevent sediment fouling of the pipe and provide a long lasting substrate for reduction of the contaminants.

The two recirculation wells are designed to create a recirculation loop to facilitate the expansion of the anaerobic conditions necessary for the bioremediation of VOCs and perchlorate. On average, the pumps operate at 1.5 gallons per minute (gpm) (7.6 Lpm) during on cycles, approximately 12 hours per day. Startup of the active recirculation system began on October 2002 for the southern IT system and September 2004 for the northern system, with both systems operational to date. Refer to Figure 1 for a plan-view of the IT system and Figure 2 showing a geologic cross-section of the IT system.

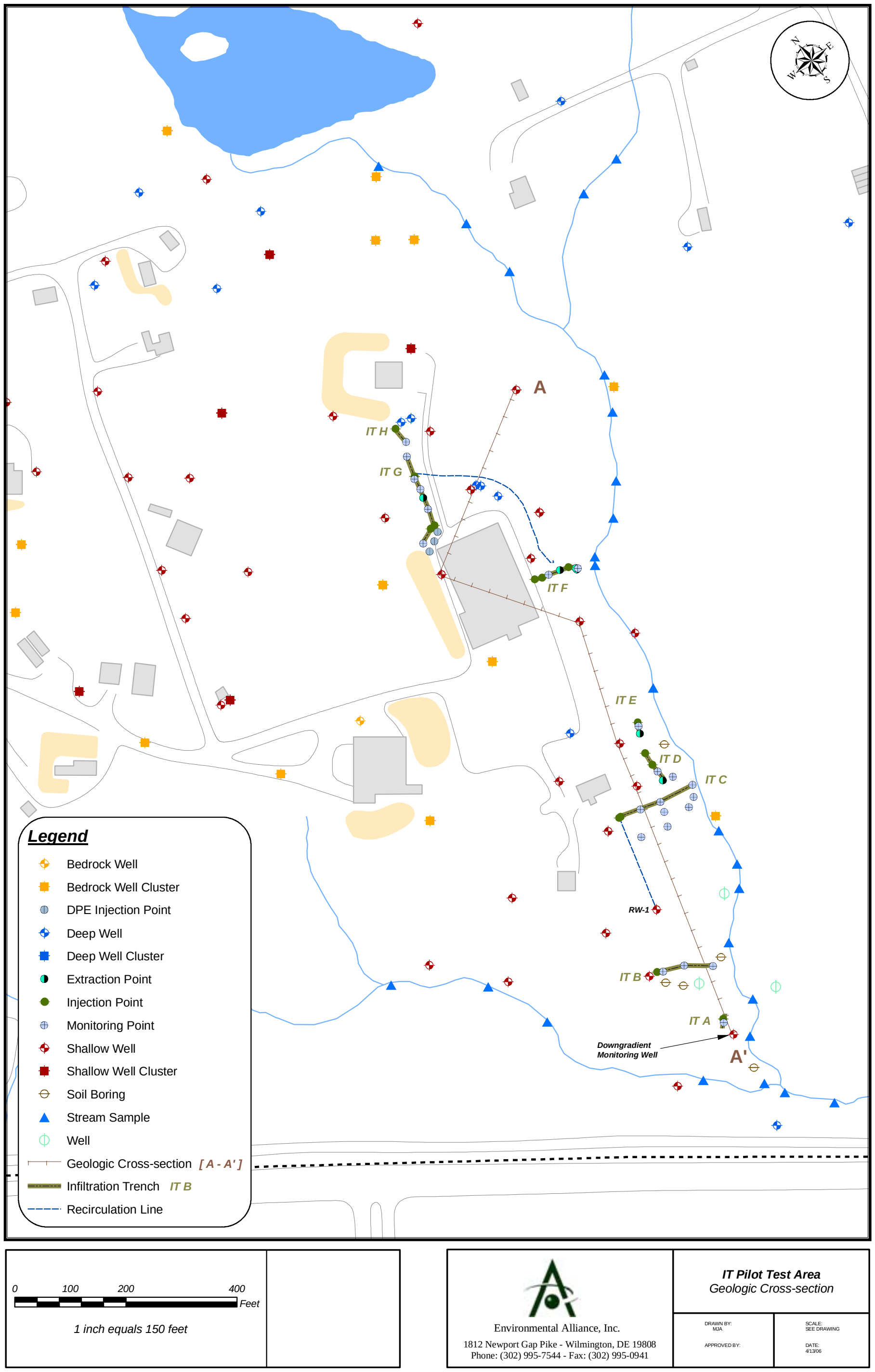

FIGURE 1. Plan-view of infiltration trench system and location of geologic cross-section.

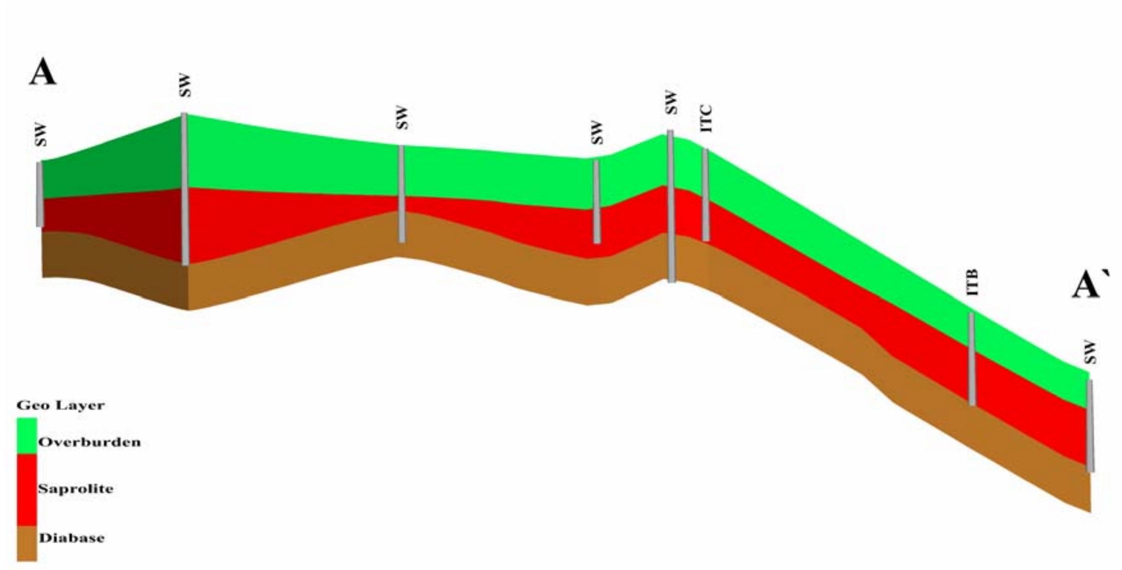

FIGURE 2. Geologic cross-section of pilot test area showing trenches B and C.

A monitoring system was established that incorporates several points installed during the site investigation as well as existing shallow groundwater monitoring wells to monitor the upgradient and downgradient groundwater geochemistry around the infiltration trenches as well as the progress of bioremediation of perchlorate and VOCs (refer to Figure 1). Routine monitoring of the infiltration trench pilot study area was conducted on a bi-weekly basis for the first three months of operation and thereafter on a monthly basis. Monitoring consists of water level gauging and field measurement of the following geochemical parameters: Dissolved oxygen (DO) and water temperature using a calibrated YSI 95 DO meter; and Ph and oxidation-reduction potential (ORP) using a calibrated Hanna HI9025C meter.

Shallow groundwater samples are collected from up and down gradient monitoring wells as well as within the trenches. In addition, groundwater samples are collected periodically from the recirculation well RW-1.

Laboratory analysis includes competing electron acceptors (sulfate, and nitrate via EPA Method 300.0), selected samples for VOCs via EPA Method 8260B, perchlorate via EPA Method 314.0 and chlorate and acetate via EPA Method 300.0B. In addition, selected groundwater samples were field-analyzed for ferrous iron (Fe^{2+}) using a Hach colorimetric kit.

RESULTS AND DISCUSSION

The Infiltration Trench remedial system can be viewed as a single system divided into components, with an upgradient influent and a downgradient effluent. Both the field and laboratory data throughout the monitoring network showed the infiltration trench system to be very effective. When viewing this remedial system as a whole, both perchlorate and the VOC analytical data collected as of November 2005 indicates that the anaerobic reduction of perchlorate and total VOCs is progressing even better than expected.

The initial DO concentrations prior to initiation of bioremediation activities indicated a predominantly natural aerobic environment with an average of 4 mg/L throughout the IT pilot test area that is typical of shallow groundwater in this area. The average DO level collected in the field (down well) both inside and outside the trenches, in November 2005 for most of the IT pilot test area indicates < 1 mg/L of DO. This is an excellent indication that an anaerobic environment is being maintained.

The 99% reduction of perchlorate downgradient of ITC from 2.19 mg/L to non-detect at a downgradient monitoring point approximately 50 feet (15.2 m) from the trench that coincides with a 71% reduction of sulfate from 72 mg/L to 21 mg/L. These decreases are excellent indications that anaerobic reduction is occurring within and downgradient of ITC. Total VOCs have also declined at this monitoring point from 317 μg/L to 105 μg/L, a decrease of 69%.

Considerable perchlorate reduction has been indicated at the most downgradient monitoring point of the IT system. Perchlorate in groundwater at this location, prior to installation of the infiltration trenches was 2.4 mg/L in September 2002, while the laboratory data collected in the November 2005 sampling event shows perchlorate at 0.008 mg/L. This represents a 99% perchlorate reduction since installation of the ITs, another positive indication of the IT system's effectiveness. In addition, nitrate at this monitoring well has reduced from 1.1 mg/L to less than 0.48 mg/L (at least a 56% decrease), and sulfate has decreased from 63 mg/L to 33.5 mg/L (a 47% decrease) indicating that the subsurface anaerobic environment is vigorous enough to reduce these competing electron acceptors.

Again, when viewing the remedial system as a whole, the VOC analytical data collected as of November 2004 indicates that the anaerobic reduction of PCE and daughter products is progressing better than expected. At the monitoring well upgradient of ITC the total VOC concentration was 356 μg/L, while at the most downgradient monitoring well of the trench system, the total VOC concentration was 33 μg/L. This indicates a 91% decrease across the southern IT system.

The laboratory analytical data for this monitoring location has also indicated significant reductions in total VOCs over time. The pre-pilot test concentration at this location in September 2002 was 189 μg/L and as of the November 2005 sampling event the total VOC concentration was 63 μg/L. This represents a decrease of 67% of total VOC's in the three-year operation of the southern trench system pilot test, an excellent indication of the vigorous reducing conditions generated by the trench system. Please refer to Figure 3 for a graphical presentation of the perchlorate and VOC data over time.

In conjunction with the IT pilot test and in the same area, Alliance has conducted the direct injection of substrate into the shallow groundwater in a small residual source area with elevated PCE concentrations that had been as high as 88 mg/L as recently as November 2002. PCE concentrations for November 2005 now indicate only 4 mg/L a 95% reduction after three years of quarterly substrate injections with a considerable reducing trend being observed since May 2003.

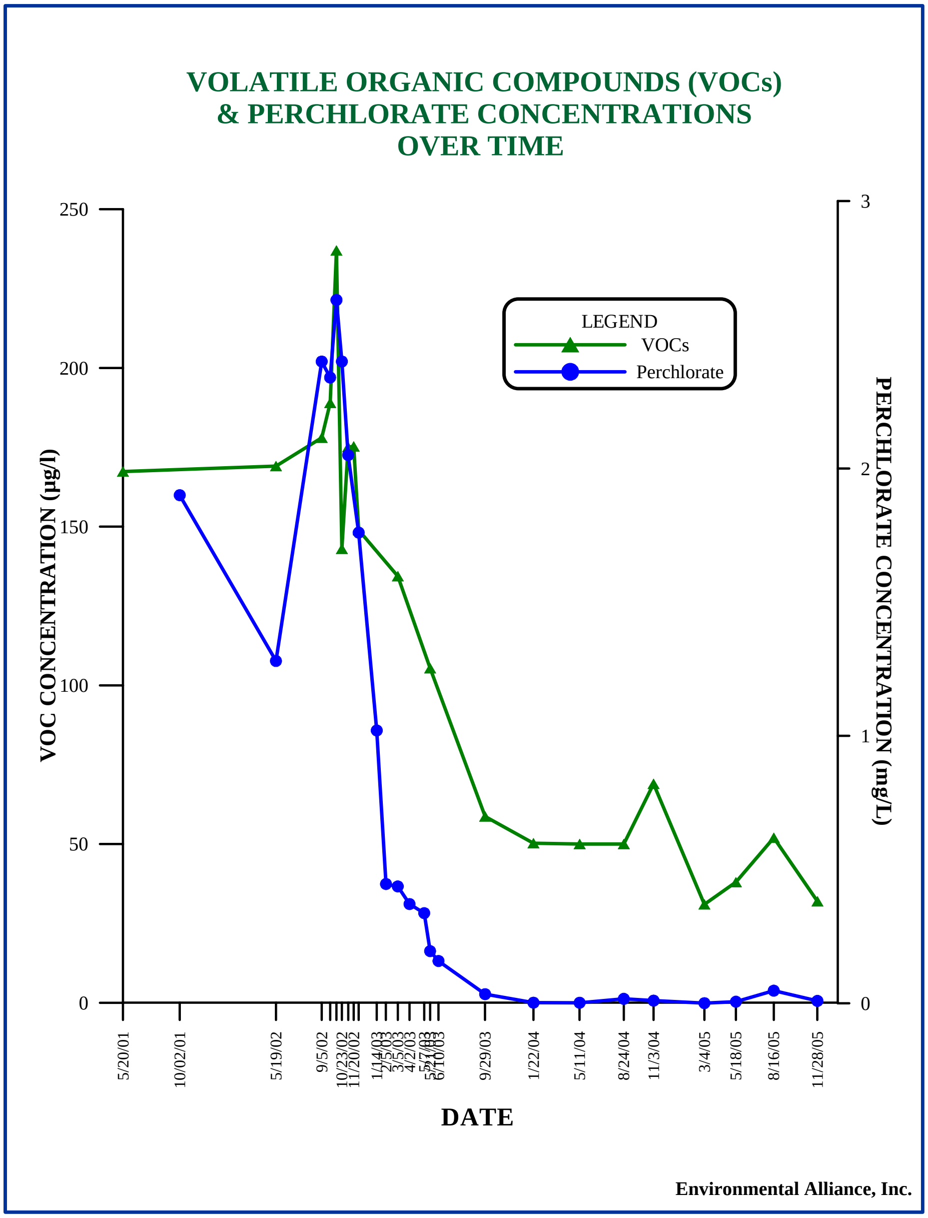

FIGURE 3. Total VOCs and perchlorate in downgradient monitoring well.

Laboratory data collected from the surface water of the north-south stream indicates that the stream is benefiting from the reductions in the residual contaminants in the shallow groundwater coming from the IT pilot test area. Total VOCs have been reduced from a high of 36 µg/L in May 2002 to non-detect for the last three quarterly sampling events at the STR-04 location just prior to exiting the facility. Perchlorate has also reduced from a high of 109 µg/L in November 2001 to 22 µg/L, a reduction of 80%.

The primary lines of evidence indicating the overall bioremediation system effectiveness and that an anaerobic reducing environment is being maintained for the infiltration trenches are the pronounced reductions of perchlorate, competing electron acceptors (DO, nitrate and sulfate) and particularly PCE and daughter products (TCE, cis-1, 2–DCE and VC) in the downgradient shallow groundwater.

CONCLUSIONS

The following additional items are to be initiated to gain a better understanding of the mechanisms related to the reduction of the chlorinated solvents and perchlorate as well as to optimize the effectiveness of the IT system prior to full-scale application:

- Collect soil samples downgradient of the individual trenches to determine effects on the impacted shallow soils.
- A bioassay of the shallow groundwater; to include polymerase chain reaction (PCR) and volatile fatty acid (VFA) analysis, to obtain a more precise understanding of the microbial mechanisms responsible for the accelerated biodegradation occurring in this area.
- Changing the substrate injection to include a combination of environmentally safe substrates such as methanol, CMA, and citric acid and/or other substrates that include lactate, denatured ethanol, acetate, and emulsified edible oils.
- Perform a tracer test to determine and quantify if the ITs and recirculation system can increase the rate of groundwater flow through the shallow soils.
- Review calculations to determine rate of contaminant degradation per day and estimate an optimum treatment zone length parallel to groundwater flow.

As the substrate injections both directly into the shallow groundwater and the ITs continue, the subsurface anaerobic reducing conditions within and around the source area will be maintained. This maintenance of the anaerobic reducing conditions will assure the continued reduction of the remaining residual VOCs and perchlorate to risk based levels that are protective of human health and the environment. As the laboratory data indicates, this will also help to mitigate additional VOC and perchlorate impacts from the shallow groundwater area to the stream. Further more, Alliance is recommending the application of this technology at other areas of the facility with similar VOC and perchlorate contamination in shallow soils and groundwater based on the significant reduction in VOCs and perchlorate in the pilot test area indicating the effectiveness of the ITs.

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