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Bioremediation System Integration to Contain/Treat a Known Perchlorate Source Area

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ABSTRACT: The anaerobic reduction of perchlorate via stimulated indigenous bacteria is becoming a widely accepted method for the bioremediation of perchlorate-impacted soil and groundwater that can be applied to storm water as well. A full-scale, integrated containment/treatment bioremediation system was designed and constructed to address storm water and groundwater prior to migration away from a known perchlorate source area within an industrial Facility. The integrated system also provides treatment of perchlorate-impacted shallow soils. The integrated system incorporates a 20-foot deep (6-meter) infiltration trench and shallow collection trenches to divert storm water into a retention basin. The retention basin is designed to simulate a naturally occurring anoxic pond, complete with native flora and fauna. A submersible pump was installed in the retention basin to both prevent run-off and to recirculate anoxic/anaerobic pond water into the infiltration trench as an additional substrate. The integrated system encompasses a treatment area that is approximately 2 acres (8,094 m^2) and has significantly decreased perchlorate concentrations in storm water by almost 70 %. Concentrations in groundwater have been reduced by approximately 80%. The minimal operation and maintenance of the integrated system has allowed for the continued use of the building with no loss of operation time.

INTRODUCTION

Field activities associated with a surface water investigation were initiated following completion of a new Facility drainage map, which identified the main drainage paths and their relation to known perchlorate source areas. The Facility drainage map was updated through survey data, GPS, aerial photography, and onsite observation to support the investigation to determine the potential impact to stormwater from the known perchlorate source areas.

Interim measures were developed for one of the source areas that incorporates several successful key elements gleaned from bioremediation pilot test activities at the source area from 2001 to 2002. The interim measures were designed to provide source control and treatment for perchlorate in surface water prior to leaving the facility boundaries along the northern drainage path. Source control is provided by the collection and treatment of surface water emanating from the known source area in conjunction with the treatment of perchlorate-impacted soil (i.e., the impacted shallow clay 1.5 to 4.6 meters bgs), and groundwater (perched and shallow) that may continue to act as an ongoing source for perchlorate impacts to surface water leaving the Facility.

METHODS AND MATERIALS

Infiltration Trench. An infiltration trench was designed and constructed to address the soil (i.e., shallow clay 5-15 feet or 1.5-4.6 meters bgs), groundwater (perched and shallow), and storm water in the known source area. The infiltration trench (IT) is located approximately 50 feet (15.2 meters) up-water table gradient of the source area and is oriented in a north, south direction. The dimensions of the IT, as constructed, are 180 feet (54.9 meters) long by 3 feet (0.9 meters) wide by 17 to 20 feet (5.2 to 6.1 meters) deep. A 3-foot (0.9 meters) high berm was constructed that surrounds both the IT and the collection trenches to prevent upgradient water runoff from entering the area while facilitating the collection of localized surface water runoff into the IT and the collection trenches.

The top 3 feet (0.9 meters) of soil excavated, was field-screened with an Ion Selective Electrode (ISE), and confirmed by laboratory analysis, to be suitable for use in the construction of the berm surrounding the IT. The IT was excavated through the shallow impacted clay to the top of the more permeable sand/gravel zone, found to be approximately 17 feet deep (5.2 meters). Two, 20-foot deep (6.1 meter) sumps were excavated into the bottom of the trench, to facilitate the distribution of substrate into the shallow groundwater of the perchlorate source area. Approximately 300 cubic yards (229 m^3) of perchlorate-impacted shallow clayey soils were mixed with mulch and transported to an onsite biocell for treatment.

Two overlapping flexible black-poly leach pipes connected to vertical risers were installed within the trench. These leach pipes are designed as horizontal injection lines to allow for injection of a soluble substrate, increasing the potential treatment zone length parallel to groundwater flow downgradient of the trench. The trench was backfilled to the surface with a 60/40 gravel to mulch mix, with the mulch acting as a long-term substrate to stimulate the reduction of perchlorate. A monitoring point was placed in the first sump to allow for sampling of groundwater within the IT.

One of the horizontal injection lines was set at approximately 14 feet (4.3 meters) below ground surface (bgs) and connected to an extraction well approximately 100 feet (30.5 meters) downgradient of the trench. The other horizontal injection line was set at approximately 7 feet bgs (2.15 meters) and connected to the retention pond sump approximately 286 feet (87.2 meters) downgradient of the IT. The two separate leach pipes overlap horizontally, approximately 20 feet (6.1 meters) in the center of the trench and allow for the injection of water and substrate from both the extraction well and the retention pond sump-pump. The configuration for the extraction well was maintained from the previous pilot test such that the line from the extraction well to the IT can be amended with substrate, sampled from a port and has an inline flow-meter to record the flow rate and amounts of groundwater pumped into the IT from the extraction well. The retention pond sump pump is also connected with a similar configuration.

Shallow collection trenches were installed north and south of the source area. The collection trenches are approximately 3 feet (0.91 meters) wide by 5 feet (1.5 meters) deep and backfilled to ground level with gravel. The collection trenches were excavated and graded to drain storm water into the retention pond.

The collection trench berms are connected to the IT berm to form a complete barrier to prevent upgradient surface water run-off from entering the trenches while facilitating the drainage of localized surface water and perched water from the perchlorate source area into the retention pond for containment and treatment. Please refer to Figure 1 for a plan view of the complete integrated bioremediation system.

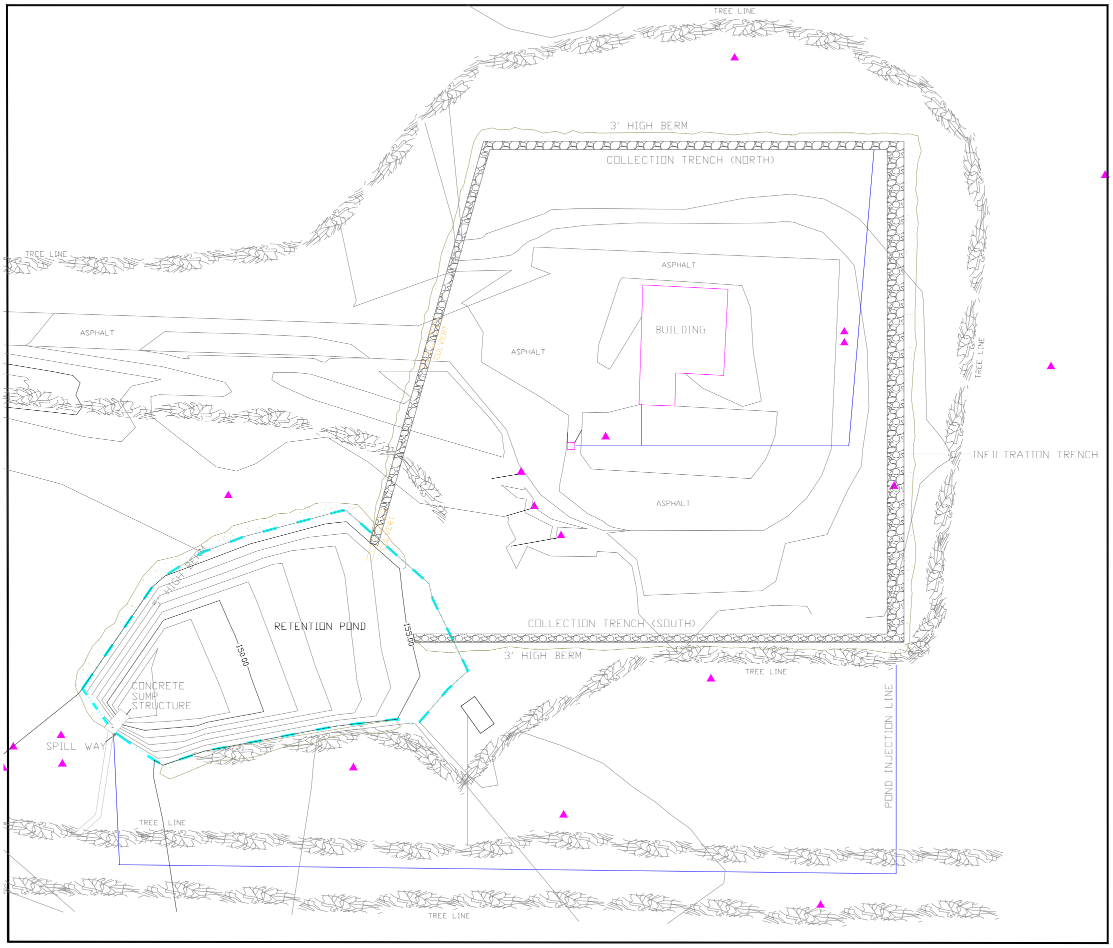

FIGURE 1. Plan-view of integrated bioremediation system surrounding the source area.

Retention Pond. All storm water and perched groundwater is directed into the wet retention pond located southwest of the source area as illustrated in Figure 1. The dimensions of the basin are approximately 130-feet long by 85-feet wide (39.6 by 25.9 meters), with a maximum depth of 11-feet (3.4 m). The pond is sized to accommodate an estimated 50-year storm water runoff of an eight-inch rainfall (20.3 cm) and perched groundwater in the perchlorate source area (approximately 1 acre or 4047 m^2).

Prior to excavation of the pond area, all vegetation was removed and staged, with any wood larger than eight-inches (20.3 cm) hauled offsite and the remaining wood mulched for use in the basin as a long lasting substrate. After tree and stump removal, a grid was established to characterize the perchlorate impacts to soil. This soil characterization (from the field-ISE and verified with the Laboratory analysis using EPA method 314.0) indicated that the soil from the surface down to 4-feet (1.2 m) was suitable for use in the construction of the berm surrounding the pond. The shallow clay that was found beneath the topsoil indicated some perchlorate impact and was used to line the pond to minimize the infiltration of perchlorate-impacted surface water while remaining within the boundaries of the pond for treatment.

The pond boundary begins approximately thirty-feet (9.1 m) downgradient of a perchlorate impacted shallow monitoring well and was excavated starting at 2-feet (0.6 m) bgs with a thirty-degree slope down to 11-feet bgs (3.4 m). The basin was constructed such that a shallow vegetated zone can be established during the dry season in the shallow portion of the pond that receives the discharge from the collection trenches. The normal growth/death cycle of the vegetated zone provides additional organic matter to promote the biodegradation of perchlorate within the pond. The bottom of the basin gradually slopes downwards away from the vegetated zone towards the sump.

Upon completion of the pond excavation, a six-inch (15.2 cm) layer of mulch generated from the tree removal of the pond area was placed across the floor of the pond as a long lasting organic substrate to facilitate the anaerobic/anoxic environment in the pond water necessary for the reduction of perchlorate. Next, a one-foot (0.3 m) layer of gravel was placed across the floor of the pond to increase the surface area of the bottom floor of the pond by several orders of magnitude, thus increasing the potential microbial population in the deeper anaerobic environment in the pond

A 4 by 6 by 10-foot sump/spillway (1.2 by 1.8 by 3 meters) was installed in the deepest portion of the pond. The sump/spillway serves to collect pond water from the deep end of the pond for pumping upgradient into the IT while also serving as a spillway in the event of over-filling of the pond. The spillway feeds into the original drainage path for the area. A 1 horsepower submersible sewage pump was placed in the bottom of the sump on an 8-inch (20.3 cm) cinder block to prevent blockage and is connected to a 1-inch (2.5 cm) discharge line leading to the IT. A check-valve and flow meter were installed in-line to aid in the pumping of water and determining flow data respectively, into the IT. Several shallow groundwater monitoring wells surround the retention pond and are monitored monthly to determine what impact the pond may have on the shallow groundwater.

RESULTS AND DISCUSSION

Infiltration Trench. The monitoring points for the IT include a monitoring point located in the southern end of the trench, screened from 5 to 20’ (1.5 to 6.1 m) bgs, a shallow groundwater monitoring point and a vadose zone monitoring point both located approximately 15-feet (4.6 meters) downgradient of the IT. Groundwater samples are collected at these points monthly and analyzed for perchlorate, chlorate (degradation daughter product) and acetate (substrate).

The two down gradient monitoring points were included in the monitoring network for the original area pilot test. Perchlorate concentrations at these points during the pilot test of 2002 were as high as 1300 mg/L and 951 mg/L at the shallow groundwater and vadose zone points, respectively. Since initiation of the IM, the perchlorate concentrations have fluctuated in both monitoring points. However, a significant decreasing trend in perchlorate concentrations has been observed when comparing the highest perchlorate concentration data from the pilot test at these monitoring points with the March 2006 data. These data indicated 344 mg/L in the shallow well and 8.59 mg/L in the vadose well. This represents a 74% and a 99% reduction in the shallow and vadose monitoring points, respectively.

The monitoring point located within the IT has indicated little to no perchlorate in groundwater inside the trench itself, with a high concentration of 1.09 mg/L detected December 2003, and 0.032 mg/L in September 2004 with no detectable perchlorate.

These data collected from the monitoring point inside the trench and the down-gradient monitoring points are good indications of the extent of the IT treatment zone. Figure 2 presents a cross-section view of the integrated system and a conceptual view of the potential treatment zones generated by the IT and the Retention Pond.

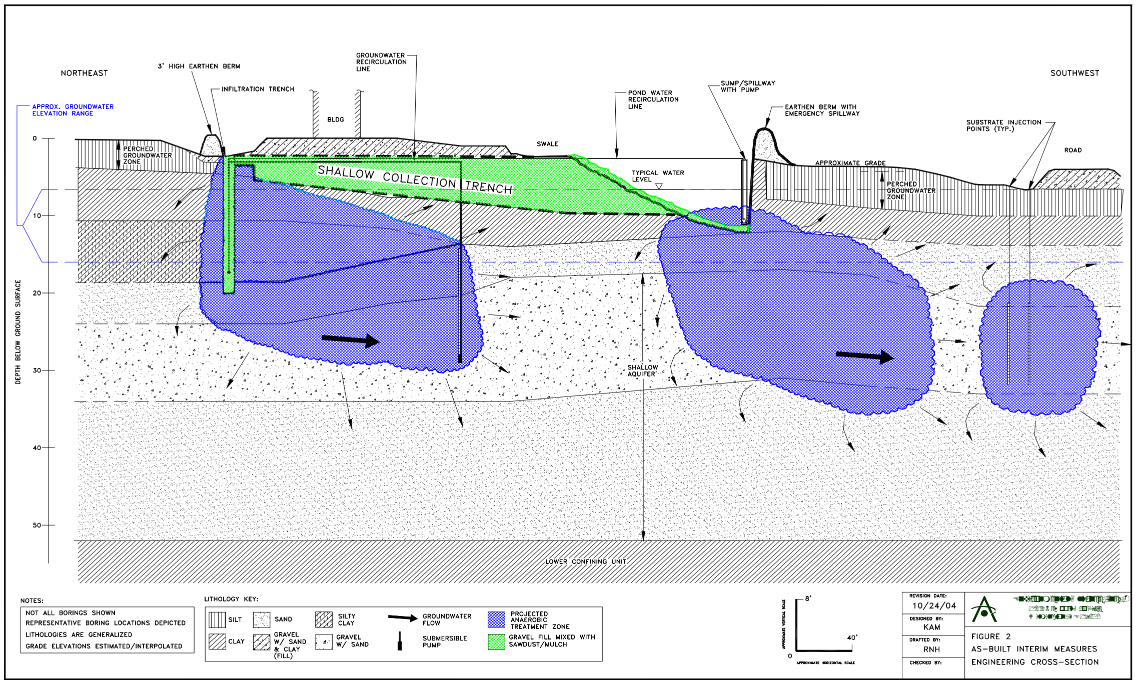

FIGURE 2. **Cross-section of as-built integrated bioremediation system.**

Collection Trenches. During several rain events water was observed draining from the collection trenches into the pond indicating the capture and drainage of the storm water run-off from the perchlorate source area into the retention basin as designed. Water samples collected in the perched monitoring points around the collection trenches that had indicated perchlorate as high as 1.26 mg/L are now non-detect, another indication that the perched water is no longer migrating from the source area and is being directed into the pond as designed.

Retention Pond. The pond filled with storm run-off water from the end of construction in August 2003 until its full capacity was achieved in June of 2004. Pumping in the pond began in March of 2004 when the water level in the pond was sufficient to commence pumping and continued until September of 2004 when the water level in the pond had dropped to less than half the ponds capacity. Pumping restarted in November 2004 with the onset of the wet season. The optimum water level in the pond is at least half of the pond's capacity in order to maintain the anaerobic conditions in the base of the pond. The sump pump was shut down three times for maintenance and was replaced once during the

30-month period, pumping over 5,500,000 gallons (20, 819,326 liters) of water at a rate of approximately 8-10 gpm (30.1 Lpm).

When applying the USDA tr55 Guidance document *Urban Hydrology for Small Watersheds* to the total annual rainfall of 52 inches for the area, a potential value of approximately 2,462,000 gallons (9,319,487 liters) of rainwater is calculated as annual run-off within the perchlorate source area, with approximately 2,000,000 gallons (7,570,664 liters) annually being recirculated out of the pond and into the IT and approximately 262,000 gallons (991,757 liters) left in the pond. This indicates a net loss of approximately 200,000 gallons (757,066 liters) of rainwater for a one-year period or just over 10% of the total potential run-off. This amount can be accounted for by evaporation and minimal infiltration of the pond water through the bottom of the pond and according to the TR55 is a reasonably expected loss of water.

Data collected from the pond water have indicated conditions that are conducive to the reduction of perchlorate, with a stratification of dissolved oxygen (DO) levels. The DO levels are higher at the surface (ambient air interface) of 3.7 mg/L and become considerably more anaerobic in the deeper zone of the pond (typically less than 0.30 mg/L). The perchlorate concentrations collected from the pond support that anaerobic conditions exist that are facilitating the reduction of perchlorate within the pond. With the onset of the wet season (elevated storm water run-off) and cold temperatures in the month of November the perchlorate concentrations in the pond increase slightly. This was first observed from November 2003 to May 2004 with the average perchlorate concentration in the pond of approximately 0.2 mg/L. The subsequent perchlorate concentrations in the pond during the dry season from June to November 2004 were all less than the detection limit of 0.004 mg/L. The warmer summer temperatures as well as the low DO levels and available substrate in the pond probably promote this reduction of perchlorate. This trend continues during each dry season. With each successive wet season the average perchlorate concentrations have decreased. The 2005 wet season from November 2004 to May 2005 the perchlorate concentration averaged .06 mg/L. The 2006 wet season continues that decreasing trend with an average concentration of .032 mg/L from October 2005 to March 2006. This average concentration represents an 84% reduction over the 30-month operation of the integrated system.

To determine the effectiveness of the collection/treatment of the source area storm water runoff, water samples were collected at the boundary of the northern drainage path of the Facility. Surface water samples are collected on a monthly basis and analyzed for perchlorate. Only those samples collected during the colder months of the wet season (typically December to March) indicate measurable amounts of perchlorate in the surface water at the outfall of the northern drainage path. The following data indicates the reduction of perchlorate concentrations in the surface water since installation of the integrated system:

- December 2002 – 0.055 mg/L,
- December 2003 – 0.043 mg/L,
- December 2004 – 0.009 mg/L,
- December 2005 - <0.004 mg/L

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Data collected in March 2006 indicated 0.012 mg/L of perchlorate compared to a high perchlorate concentration of 0.128 mg/L in March of 2003. This represents a reduction in the concentration of perchlorate at this sampling location of 91%.

One of the original Facility wells, located approximately fifty feet (15.24 meters) downgradient of the pond, has recently been indicating the lowest perchlorate levels since monitoring began in 1993. The lowest concentrations in this well were observed after installation of the integrated system. Historical data at this location had indicated perchlorate as high as 85 mg/L. Figure 3 presents the groundwater data collected during the operation of the integrated system and illustrates the downward trend in perchlorate.

The dissolved oxygen levels have also remained consistently low in the monitoring wells downgradient of the integrated system, at less than 0.3 mg/L, another indication that the pond is helping to generate anaerobic conditions and the reduction of perchlorate in the shallow groundwater downgradient of the pond.

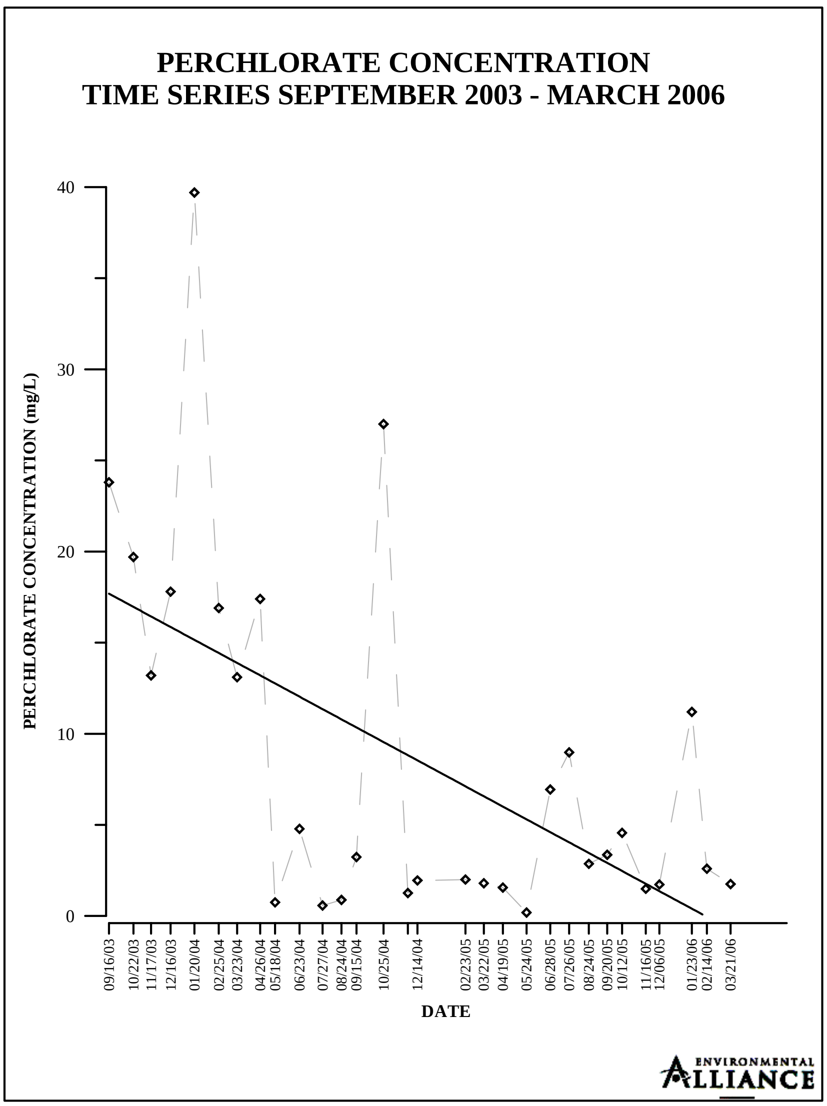

FIGURE 3. Perchlorate over time in downgradient groundwater monitoring well.

CONCLUSIONS

The laboratory and field monitoring data for the individual components of the integrated system surrounding the source area have indicated that the system is performing as designed. The main objective of the IMs to mitigate the offsite releases of perchlorate in the storm water from the known source area has been achieved with the significant reduction of perchlorate in the storm water of the northern drainage path with reductions seen in groundwater as well.

The following additional items are recommended to gain a better understanding of the mechanisms related to the reduction of perchlorate in the pond and shallow groundwater as well as continuing to address the residual perchlorate in the source area:

- Collect soil samples downgradient of trench system to determine effects of integrated system on the impacted shallow clayey soils.
- Perform bioassay of microbial population in retention pond to better characterize and qualify the perchlorate reducing capacity and rate limiting factors related to the reduction of perchlorate in the pond.
- Remove additional sump adjacent to building source area that may be continuing to act as a residual source area for perchlorate in groundwater.
- Develop calculations to determine rate of perchlorate degradation per day and estimate an optimum treatment zone length parallel to groundwater flow.

These additional items are essential in order to potentially increase the overall performance of the integrated bioremediation system with the ultimate goal of continuing to mitigate perchlorate impacts to surface water while providing treatment to the residual perchlorate source area. This treatment technology may also be useful for other areas of the Facility with similar perchlorate impacts.

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