

# LNAPL Remediation via Horizontal Biosparging Wells Facilitates Property Redevelopment

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**ABSTRACT:** A former manufacturing facility was closed, demolished, and subsequently sold to a commercial property developer. Site investigations discovered two areas of light non-aqueous phase liquids (LNAPL) and corresponding constituents of concern in soil, including toluene and toluene derivatives. Biosparging using horizontal wells was selected as the preferred alternative based on its potential effectiveness, low cost relative to other approaches, and low amount of impact to future property redevelopment plans. The remedial objective was to remove the LNAPL and enhance the natural aerobic biodegradation of toluene and other compounds.

Two horizontal biosparging wells were designed, permitted, and installed. Design was completed using proprietary software to select the well slot sizing needed to achieve a reasonably even airflow distribution across the well screen. The directionally drilled horizontal wells were approximately 1,130-feet long, 48-feet deep, and constructed of 6-inch diameter HDPE casing equipped with 520 feet of custom-slotted well screen. Prior to well installation, the State required the wells to be permitted. Complying with the State's well construction specifications presented a unique challenge for installing the wells.

Individual air delivery systems were designed, fabricated, and installed for each well. Each air delivery system consisted of a 30-horsepower positive-displacement blower, air-to-air heat exchanger, and electrical controls delivered to the site pre-installed inside an 8 by 14 foot wooden shed. Each blower is capable of delivering 260 cubic feet per minute (cfm) at a pressure of 9.7 pounds per square inch (psi).

During the operation of the remedial system, performance monitoring included (1) ground water elevation measurements using pressure transducers (during startup and also during a planned shutdown), (2) Light non-aqueous phase liquid (LNAPL) thickness measurements, (3) ground water sample collection and analysis on a quarterly basis for volatile organic compounds (VOCs) and permanent gas parameters, (4) soil gas sample collection and analysis for VOCs, and (5) in situ measurements of dissolved oxygen. Each of the parameters monitored were necessary for evaluating the overall performance of the remedial system. The biosparging system operated from May 2003 to August 2004 and was successful in achieving the project objectives of remediating free and residual LNAPL.

## INTRODUCTION

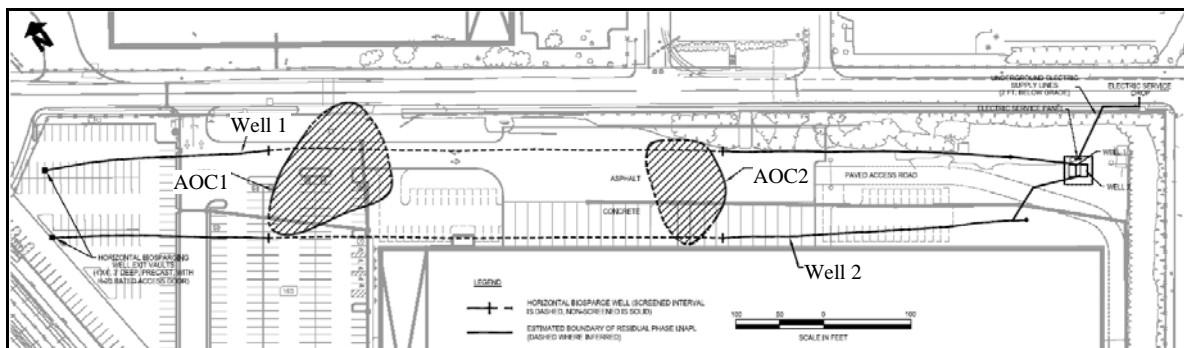
A properly designed and operated biosparging system can remediate ground water and soils through the addition of oxygen to facilitate biodegradation while minimizing losses through volatilization. For these mechanisms to be effective there must be contact between the injected air and the impacted ground water and soil. Therefore, in order to ensure the proper performance of a biosparging remedy an understanding of the

distribution of air within the subsurface and its potential migration pathways is of fundamental importance. As noted by Tomlinson et al. (2003), air movement within granular aquifer media occurs primarily within continuous air channels, and the formation of these air channels is controlled by both small and large-scale heterogeneities. As the injected air pressure increases, the air within the formation will preferentially flow through the pores with the lowest entry pressure, which are typically the higher permeability portions of the aquifer. Therefore the overall pattern of airflow is generally controlled by permeability variations (Tomlinson et al., 2003).

Within a heterogeneous aquifer such as this study site, the injected air will rise vertically until it reaches a capillary boundary such as a tight sand, silt or clay lens, where it will collect and form an air pocket on the underside of the lens (Tomlinson et al., 2003). The air pressure (i.e., capillary pressure) under this lens will continue to increase until the air pressure exceeds the entry pressure of the lens, or until another pathway for the air pocket evolves (e.g., well casing, stratigraphic window, or the edge of the lower permeability lens). Therefore, heterogeneity causes the air to spread laterally (Ji et al., 1993; Thomson and Johnson, 2000) with elevated air saturations forming beneath the lower permeability lenses (Lundegard and LaBrecque, 1998; Tomlinson et al., 2003).

The objective of this work was to verify that the horizontal biosparging system (i.e., system) was able to meet the project objectives. The project objectives were to remediate free and residual LNAPL observed in the soil profile (near the soil-ground water interface) and monitoring wells, through enhancing the natural aerobic degradation of the petroleum hydrocarbons in soils. The horizontal well installation and construction and the tools used to monitor the operation of the system and to assess the overall performance during its first 16-months of operation are discussed. The system was operated from May 2003 through August 2004. Operational testing of the system was completed in January 2003 prior to system startup with additional performance monitoring sampling collected after system shutdown.

**Background.** The former manufacturing facility was decommissioned, and environmental investigations were performed in accordance with the State agency requirements. Two areas of LNAPL were discovered, along with a 500-foot wide dissolved-phase VOC plume in ground water between them. The primary constituents of concern included toluene, toluene derivatives, and other organic compounds. vadose zone and shallow saturated zone soils consisted of fine to medium grained sands throughout with silt and clay lenses/stringers in the western area of the site. Ground water



**FIGURE 1. Location of horizontal wells and areas of concern.**

is observed at a depth of approximately 40 feet below ground surface.

After the former manufacturing structures were razed, the property was sold to a commercial property developer and warehousing facilities were constructed in the vicinity of the impacted ground water plume and residual LNAPL. To accommodate beneficial reuse, a remedial approach was required that would not impact the new site operations. Biosparging using horizontal wells was selected as the preferred alternative based on its potential effectiveness, cost effectiveness to other approaches, and low amount of impact to new site operations. Figure 1 shows the location of the two LNAPL areas of concern (AOC1 and AOC2) with respect to the horizontal wells and other warehousing structures at the facility.

### **BIOSPARGING SYSTEM DESCRIPTION**

The installation of two horizontal biosparging wells (Well-1 and Well-2) was completed in January 2002, each well was constructed with approximately 1,200 feet of 6-inch diameter high-density polyethylene (HDPE), including an approximate 500-foot slotted (i.e., screened) interval. The wells were installed parallel to each other with the screened intervals spaced approximately 100 feet apart, across their entire lengths (see Figure 1) so that the aeration zone of each well converged with that of the other well. The well screens were set at a depth of approximately 50 feet below grade, which is approximately 10-feet below the average water table elevation.

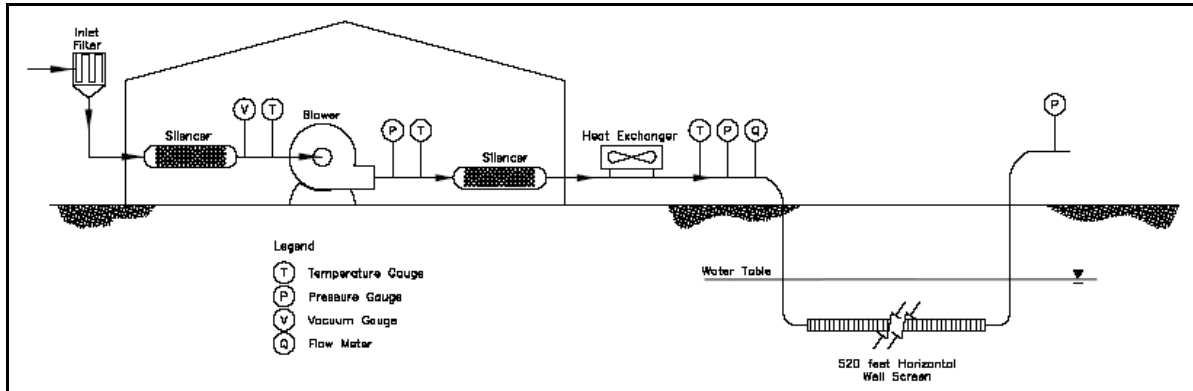
Similar air delivery components of the system were constructed for each well to operate independently of one another within their individual 8-feet by 14-feet sheds. Within each shed, is housed a rotary lobe blower powered by a 30 Hp electric motor. The air is cooled with an air-to-air heat exchanger prior to injection into the subsurface to protect the HDPE piping. The system is equipped with a pressure relief valve and silencers. The system was designed to automatically shutdown for low pressure, high pressure, high temperature and unbalances of electrical power. Additionally, the system is connected to an auto dialer that alerts of operational alarms through a phone distribution list. A schematic of the system is shown on Figure 2.

### **SYSTEM OPERATION PARAMETERS**

During system operation many parameters and conditions are monitored using various gauges and meters. These include injection pressure, temperature, and flow. Specifically, the gauges monitored are summarized as follows (See Figure 2):

- The temperature was monitored with three gauges: Prior to the blower, after the blower, and after the heat-exchanger prior to injection into the formation.
- The pressure was monitored with four gauges: Prior to the blower (vacuum), after the blower, after the heat-exchanger prior to injection into the formation, and the distal end of the horizontal well.
- The flow was monitored with one gauge located after the heat-exchanger prior to injection into the formation.

The results of this monitoring indicated that the unit operated as designed and expected.



**FIGURE 2. Schematic of horizontal well biosparging system.**

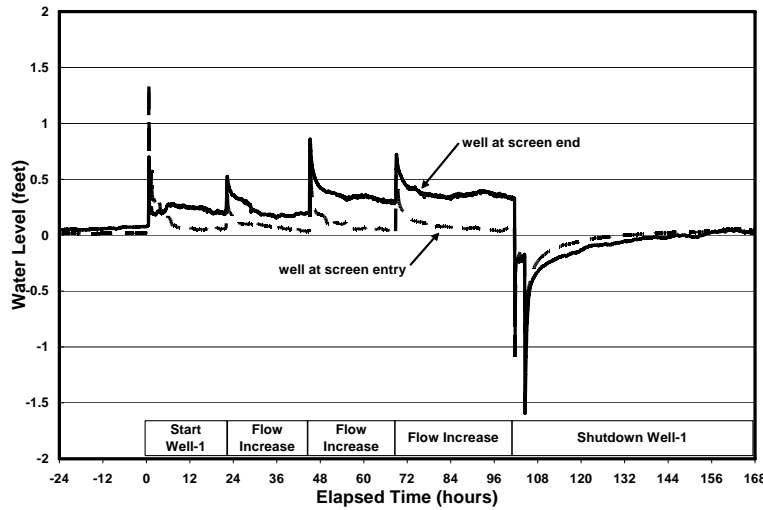
**Pressure.** The main pressure parameters used to monitor the performance were the wellhead and distal end pressure readings. The other pressure gauges were used to monitor the system for maintenance. The results of the pressure monitoring indicated that the pressure across the horizontal wells was fairly constant; thus, indicating that the air injection into the formation across the length of the slotted interval of the horizontal wells was evenly distributed. This is important as it demonstrates an absence of air short circuiting at the distal end of the slotted interval. The injection pressure for Well-2 was slightly higher than Well-1. Based on a review of boring logs from the study area, the slight increase is likely due to a finer grained soil and increased heterogeneity surrounding this well.

**Temperature.** The temperature readings for both units indicated that the heat exchanger was able to lower the injection temperature of the units. As anticipated, the temperature readings indicate that the injected temperature into the formation was higher by approximately 40°F in the summer months. Also, the temperature of the injected air into Well-2 was slightly higher than that of Well-1. Again as noted above, this is likely due to the increased injection pressure required for the well to overcome the entry pressures required due to the finer soil matrix. A higher injection pressure compresses the air more, which causes the injection air temperature to increase.

**Flow.** Based on startup testing results, the flow rate for both units was maintained at approximately 100-cfm throughout the operation period even though the units were designed for a flow rate of 260-cfm. Good air distribution was observed at this lower flow rate; thus minimizing the amount of potential volatilization. Minor fluctuations of the flow rate occurred during startup as new flow channels were developed, but after the initial few hours the flow rate stabilized and was maintained at approximately 100-cfm.

## WATER LEVEL RESPONSE

Pressure transducers were used to monitor the influence of the system on ground water levels, and were used during both the startup and again during the shutdown of the system. Prior to startup of the system, the transducers were placed in five vertical monitoring points varying from a point outside of the zone of influence to monitor background conditions, to locations closer to Well-1 or Well-2 and others located between the two wells. The transducers were within the vertical wells a few days prior and after startup in May 2003, and a few days prior and after shutdown in August 2004.



**Figure 3. Water level response.**

the monitoring points increased sharply due to changes of the flow during the startup testing, and again a sharp decrease in the water elevation once the system was shutdown. Of note is the storage of air pressure within the formation near the screen end well. Within this area of the site are tighter silt layers, which would cause this effect (Tomlinson et al., 2003). The zone of influence was estimated to be in the range of 50 to 100 feet laterally from the wells based on this data. As anticipated there was no influence observed within the background wells due to biosparging.

On average wells influenced by the system rose approximately 0.25 to 0.50 feet with instantaneous variations of water level readings varying between wells (0.3 feet to 5.25 feet). These data verify that the system delivered air across the entire horizontal well screen interval; however, these readings are a measure of the pore pressure and should not be misconstrued as changes to the actual water table elevation.

The applied pressure due to the injection of air causes an initial rapid pressure response then movement of pore water as a result of the induced pressure gradient, vapor expansion and buoyancy. This movement of pore water is resisted by the conductivity of the medium and causes excess pressure to build within the pore water. As the pore water moves away from the injection point the voids are filled with air, until the two phases reach equilibrium. The water level in a well reflects the excess pore water pressure and hence data from the wells represents the induced pressure gradient field in the water caused by the injection of air. Since the water level changes in a well represent a water phase pressure variation, it should not be confused with a physical change in the location

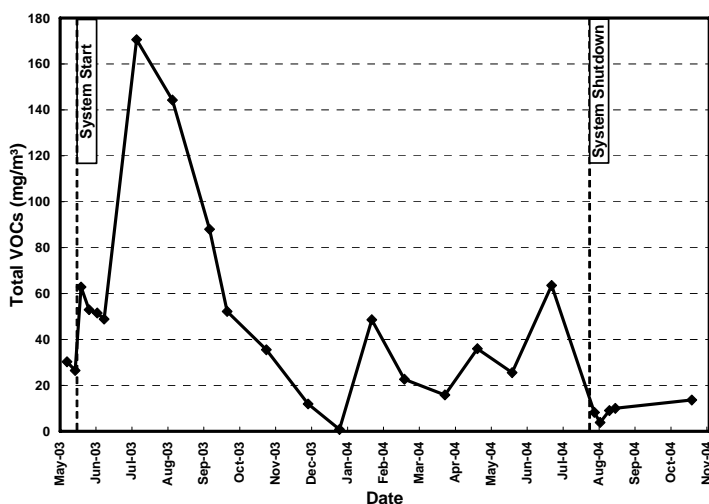
As shown on Figure 3, the influence of the system on the aquifer is evident along the length of the horizontal wells. Shown on Figure 3 are readings from two locations during the startup testing completed prior to operating the system, one location is near the eastern end (or start) and the other near the western end (or end) of the screened interval of the horizontal wells. The measured elevations within

of the water table. Thus, once the air channels have been established and steady state conditions have been reached the water level in the wells returns to the initial values or slightly higher levels if storage of air within the formation occurs. This elevated reading is just a measure of the pore pressure of entrapped air, which is typical in a layered aquifer such as this study site. During shutdown the opposite effect occurs; whereby, the voids collapse and the pore water fills these voids. This is observed as a sharp decrease in pore water pressure and then an eventual return to initial values prior to sparging. Overall, the influence on ground water flow direction is expected to be minimal.

## SOIL GAS MONITORING

Soil gas samples were collected by using tedlar bags from seven fixed sampling locations within the vadose zone. The soil gas monitoring locations are permanent 1 inch PVC probes installed to 3 feet below ground surface, with the bottom 2-foot perforated with 3/8-inch drilled holes. The annulus was filled with 1/2-inch pea gravel with a 6-inch bentonite-cement seal to surface, with a locking flush mount cover at surface.

The soil gas monitoring samples were collected from the vadose zone as grab samples into dedicated 1-Liter tedlar bags under negative pressure using a sampling pump, and a



**Figure 4. Soil gas concentration.**

concentrations typical of remedial systems from startup, the soil gas concentrations stabilized in early October 2003. The concentrations of detected constituents fluctuated but remained fairly stable until the system was shutdown on August 2004.

a vacuum chamber box. A combination PID/ FID meter was used prior to sample collection to purge and collect qualitative soil gas measurements.

Soil gas samples were collected weekly for approximately one month after the May 2003 startup and then on a monthly basis until the system shutdown in August 2004. The laboratory results for one of the sampling locations are shown in Figure 4. After the initial increase in observed

## LNAPL MONITORING

Ground water and LNAPL monitoring was completed during the operation of the system. The monitoring events were completed monthly during the first six months of operation and then quarterly thereafter. The depth to water (DTW) and depth to product (DTP) in the wells was measured from the top of the well casing to an accuracy of 0.01 feet using an electronic oil/water level indicator. Prior to startup, LNAPL was observed within three wells. Since shutdown of the system, LNAPL has not been observed within any well. Additionally, LNAPL has not been observed within site wells since September

2003 (four months of operation); thus indicating that free-phase LNAPL has been removed from the formation.

## GROUND WATER MONITORING AND SAMPLING RESULTS

A total of eight quarterly ground water sampling events have been completed at the facility as part of monitoring the performance of this remedy. Two sampling events were completed prior to initiating the system; four sampling events were completed while the system was operating; and two sampling events were completed during system shutdown to assess its performance.

Ground water samples were collected using low-flow purging and sampling methods in accordance with the United States Environmental Protection Agency (USEPA) Region II *Low-Stress (Low-Flow) Purging and Sampling* guidance document (16 March 1998). Each well was purged with the pump intake set at the approximate midpoint of the wetted screened interval. Dedicated Teflon™ tubing for the water lines and polyethylene tubing for the air intake and air exhaust lines were used for all events. The wells were purged at a rate of 0.5 liters per minute (Lpm) or less. The DTW in each well was measured prior to and after pump installation, and throughout purging. The purge rate was lowered, as needed so that the total drawdown in any well remained less than 0.3 feet throughout purging. The response field parameters were monitored during purging using an in-line water quality flow-through cell. Measurements were recorded every three to five minutes. Purging continued until the stabilization criteria were met for three consecutive measurements. Prior to sampling, the flow rate was lowered to maintain a flow between 0.1 and 0.25 Lpm. Ground water samples were collected for VOC and permanent gases analysis.

Ground water analytical results for toluene for one of the wells located near the source is shown on Figure 5 with corresponding dissolved oxygen also shown. The first post-shutdown ground water sampling event was completed in early September 2004 approximately one month after the shutdown of the system to allow the ground water sufficient time to rebound. Additionally, the next quarterly event in November 2004 was also completed while the system was shutdown to confirm the observed values.

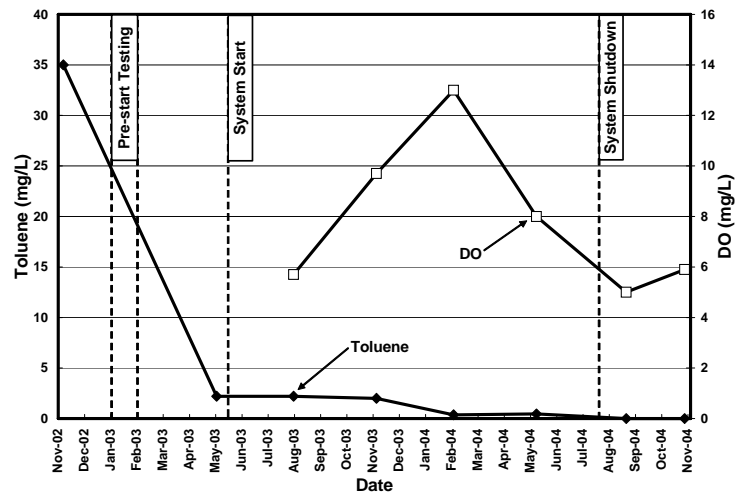


Figure 5. Toluene and dissolved oxygen.

## **SOIL SAMPLING FOR RESIDUAL LNAPL**

Four soil borings were completed; two soil borings were completed in each of AOC1 and AOC2. The borings were completed using 4 ¼-inch inside diameter (ID) hollow-stem augers with continuous sampling with 2-inch ID split spoon samplers from approximately 30 to 40 feet below ground surface (i.e., above the capillary fringe and into the saturated zone below the watertable). No free-phase LNAPL was observed within these borings; however, a minor sheen was observed on soil water of one of the split spoon samples within AOC2, and was only observed after applying pressure to the sample followed by aggressive physical agitation and vibration of the sample (i.e., agitation test) which is characteristic of low LNAPL saturation levels (i.e., residual LNAPL).

## **DISCUSSION OF RESULTS**

The system was operating for a period of approximately 16-months (i.e., May 2003 to August 2004). During that period, the monitoring results indicate that the system has met the primary objective which was to remediate the free-phase and residual levels of LNAPL within soil, and showed a corresponding reduction in ground water for VOCs associated with the free and/or residual LNAPL (i.e., toluene concentrations).

The system maintained a constant pressure of injected air across the length of the biosparging wells which resulted in an even distribution of air within the formation. The injected air was observed to have a zone of influence in the range of 50 to 100 feet from the injection wells as evidenced by the influence on water table levels along the length of the horizontal wells both with pressure transducer and interface meter readings.

Soil gas readings increased during the initial months of operating the system; however, as anticipated, these levels decreased to a fairly stable level. The soil gas concentrations began to decrease and be stable approximately four months (i.e., September 2003) after startup which was the same period when LNAPL was no longer observed within monitoring wells. LNAPL has not been observed in monitoring since that time.

During the soil investigation, no free-phase LNAPL was observed in the borings and residual LNAPL was only observed as a slight sheen on the pore water within one boring after agitation. Therefore, based on the lack of visual evidence of LNAPL in wells and soil and reduction of toluene concentrations in ground water, the system has met its primary objective.

The ground water results obtained from after shutting down the system indicate that the ground water contaminant concentrations have decreased substantially relative to the pre-startup ground water sampling results. This observed decrease in ground water concentrations continued during the operation of the system. To confirm the observed decreases in ground water concentrations, the system restart was delayed to collect another quarterly ground water samples. A majority of contaminant concentrations have only slightly rebounded, but remain well below the concentration measured prior to operating the system. Toluene concentrations within ground water have decreased in the monitoring wells to levels below the applicable State ground water standards. Toluene concentrations within ground water were observed to directly correlate with free and residual phase LNAPL levels, and therefore a measure of the success of the system with respect to the removal of free and residual phase LNAPL.

Based on the decrease of concentrations, and the general increase in dissolved oxygen, the system has been able to enhance the natural aerobic bioremediation of the aquifer.

## CONCLUSIONS

The conclusions of the performance of the system are as follows:

- The system was able to create a zone of influence of approximately 50 to 100 feet laterally (the targeted treatment area) with a constant pressure maintained along the screened interval.
- Ground water quality has shown an improvement in total VOC concentrations in select wells as compared to analysis completed prior to the system operation. Specifically, toluene levels within ground water have decreased to below the applicable State ground water standards; thus, indicating that free and residual LNAPL has been decreased (toluene is a direct measure of LNAPL presence).
- Free phase LNAPL has not been observed within monitoring wells after four months of system operation. Additionally, no free phase LNAPL has been observed within onsite monitoring wells since the August 2004 shutdown.
- No free phase LNAPL was observed within the soil borings completed after the system was shutdown. Only a slight indication of residual levels of LNAPL was observed within one split spoon sample after agitation of the sample.
- The initial soil gas concentrations indicated that the system was able to contact the contaminants of concern within the formation and that some volatilization occurred. These early levels decreased to levels below background after the first five to six months of operation and continued to remain stable until the system was shutdown. These levels subsequently decreased after shutdown.

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