# MTBE IMPACT TO DOMESTIC WELLS – INVESTIGATION, MODELING AND REMEDIATION

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## Abstract

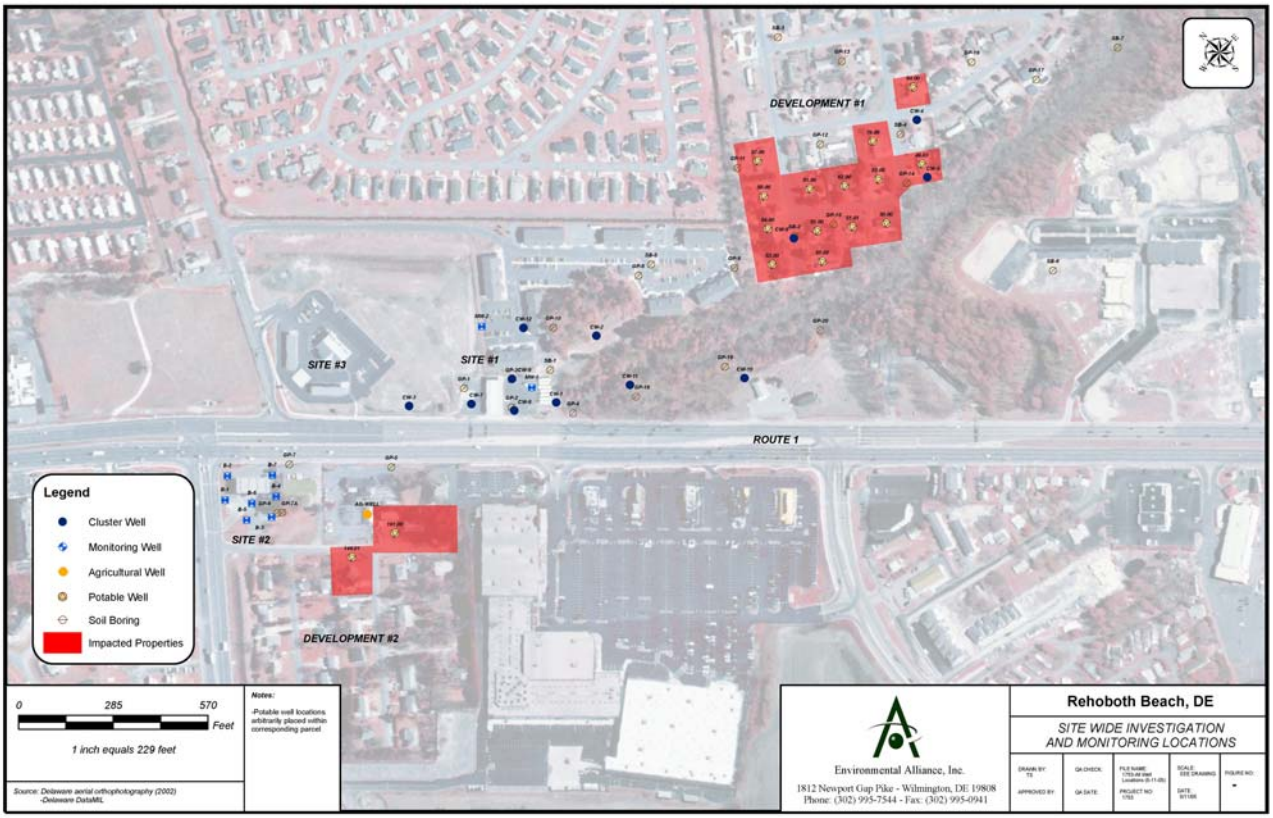
A development of homes within a beach community in Delaware has experienced potable water impact. Analysis of the wells indicated elevated levels of benzene and MtBE. Acceptable potable water was established immediately via carbon filtration. Lack of an aquitard, and the potential for salt-water intrusion, resulted in not pursuing the installation of deep potable wells. Based on what would better serve the public, an existing water line has been extended by the state to the area of impact but over 300 wells are present down-gradient.

A source area investigation is complicated by access and the presence of three gasoline retail facilities upgradient of the impacted development; two of which have been investigated (one a no further action letter and the other closure after remediation). To determine the potentially responsible parties (PRPs) the investigations included: direct push borings, geotechnical borings, and multi-level cluster wells (five per boring) to 90 feet below grade surface (bgs). The investigations have indicated that the two prior case file facilities to be the PRP's for the impact.

With source areas now under remediation (mechanically remote pulsed air sparge soil vapor extraction and periodic high vacuum events) the link to the development is being assembled through modeling and a remediation plan for the dissolved phase plume is in the design phase. Options for this deep remediation include: continued pumping to prevent further impact, muti-level pulse ozone sparging, and bio-augmentation. Due to the large horizontal and vertical area of impact, multiple source areas, the down-gradient domestic wells, and the need to provide a corrective action plan (source and deep transport zones), the scope of this project is extensive. Ultimately, the project has moved forward based on legal, financial, and corrective action obligations and by choices and decisions of the PRPs and their consultants, the impacted residents, and the state.

## MtBE Impact to Drinking Water Supplies

The process associated with identifying, investigating and addressing a MtBE impact to potable wells in areas that are heavily developed with finite groundwater resources is complex. An example of such a case involves two developments in the growing Atlantic coast community of Rehoboth Beach, Delaware (refer to Figure 1).




The area is relatively flat with a slight slope to the east/southeast at an elevation roughly 30 feet above Mean Sea Level (MSL) other than the relief associated with Munchy Branch Creek along the southern boundary of the Development #1. Development #1 consists of 102 residential properties and Development #2 consists of 30 residential properties and 3 businesses. The water source for the developments comes from wells installed at each of the individual properties. One well for a business in Development #2 is for agricultural irrigation for maintaining plants and vegetables.

Indication of a groundwater impact within the Development #1 resulted from a resident testing their well water based on objectionable taste and odor in November 2002. The analytical results showed benzene concentration of 5 to 10 µg/L and approximately 500 µg/L of MtBE.

Since 2002, Delaware's Department of Natural Resources and Environmental Control Tank Management Branch (DNREC-TMB) has initiated contact with neighboring residents to collect potable well samples in the vicinity of the impacted residential well to determine the extent of petroleum constituent impact of mainly MtBE. Upon detection of MtBE within a potable well DNREC immediately contacts a contractor from their pre-approved contractor list to install and maintain a Point of Exposure Treatment (POET) system. DNREC-TMB then developed a monitoring schedule to evaluate the POET systems and groundwater quality in the development. To date fouteen impacted potable wells have been identified in Development #1 and in June 2004 two impacted potable wells were identified in Development #2 as well as the agriculture well (refer to Figure 1).

While addressing the treatment of the residential water supply to maintain a potable water source, DNREC-TMB began a file search of their leaking underground storage tank (LUST) database and project files to identify potential source areas in the vicinity of the development. Based on the file search information, DNREC-TMB identified three locations as potential source areas for the potable well impact; two inactive LUST sites that have remained as active retail gasoline stations and one other new active retail gasoline station that has no reported releases.

Site #1 is located approximately 1,000 feet west-northwest of Development #1. Petroleum impact was noted in soil during an underground storage tank (UST) system removal/upgrade activities in February 1995. MtBE was not analyzed as part of the site UST removal and monitoring activities. The facility was granted No Further Action (NFA) in August 1998 based on a BioScreen model.

Site #2 is located approximately 1,800 feet west-northwest of Development #1 and immediately adjacent to Development #2. In May 1984, Site #2 investigation activities commenced in response to a reported release of unleaded gasoline. Remedial actions were completed by Pump and Treat (P&T) and Soil Vapor Extraction (SVE) technologies. Groundwater samples analyzed for MtBE throughout the duration of the Site #2 investigation were non-detect with the detection limits ranging from < 200 µg/L to < 2 µg/L. Closure was granted for the site by DNREC-TMB in April 1993.

Site #3 is located approximately 1,300 feet west-northwest of Development #1. Site #3 started operations as of 1999. There is no record of any releases a from the UST system monitoring performed at the site. Four monitoring wells installed as part of the site's UST system monitoring program have shown non-detectable results for gasoline constituents.

Based on the information above no potentially responsible party was identified for DNREC-TMB to issue a notice of violation to assume responsibility for conducting a hydrologic investigation. Therefore, DNREC-TMB drew upon their pre-approved environmental consultant list for conducting a hydrologic investigation and taking over the management of potable well monitoring activities under the State's budget. DNREC-TMB awarded the contract to Environmental Alliance, Inc. (Alliance). Financing of the activities conducted by DNREC-TMB and for work contracted to outside sources was provided through a state fund established from a retail gasoline facility tax base.

The management and implementation of the residential monitoring program involved adapting to residential use (year-round or seasonal) of property and the incorporation of new residential properties into the monitoring program. Constant interaction with the residents and DNREC-TMB has been required to maintain the residential monitoring program and the POET systems. Some of the items required for the monitoring program have been: arranging property access, monitoring event notification, arranging POET system installation (for newly impacted wells), scheduling POET system maintenance and change-out of spent carbon units, monitoring results reporting and addressing resident questions

**Initial Investigation Phase**

Alliance used the initial information compiled by DNREC-TMB in conjunction with data from a well search to determine the vertical extent of impact at the potable wells in the Development #1 and to understand the geology from the potential source areas. The well search found hundreds of potable wells hydraulically down gradient of Development #1 with screen intervals ranging between 46 and 80 feet bgs. A well log from Development #2 adjacent to Site #2 indicated an agriculture well screened from 64 to 74 feet bgs with a production rate of 30 gallons per minute.

Site-specific geology was initially characterized via five soil borings completed in April 2003 (refer to Figure 1) with a truck-mounted B-52 Mobile Drill rig using the hollow stem aguer (HAS) drilling methodology. Soil samples were collected at five-foot intervals above the water table and continuously below the water table to an approximate depth of 50 feet bgs. All soil samples were field screened with a PID. Two soil samples were submitted for laboratory analysis of DNREC gasoline constituents of concern (COCs) based on significant PID readings and the discretion of the supervising geologist.

The evaluation showed the presence of mostly sand with zones of variable sand percentages mixed with gravel, silt, and/or clay underlying the development area. No significant silt/clay horizon (greater than three feet in thickness) was noted to the depth investigated (maximum 51 feet bgs) that would indicate a confining layer preventing vertical movement of groundwater. Based on the geology encountered underlying the development area, the transport of gasoline constituents dissolved in groundwater should not be significantly restricted across the area, but may be slightly influenced locally. The soil screening during the geologic investigation showed no evidence of petroleum impact above the water table at the boring locations. The soil analytical results indicated the presence of DNREC gasoline COCs at a depth of approximately 32 feet bgs, but were not above regulatory levels. The other sample at approximately 22 feet bgs indicated non-detectable results.

In conjunction with the geology evaluation a discreet zone groundwater sampling event using direct push methodology was implemented to define the vertical distribution of contaminants from the potential source areas through Development #1 in May/June 2003. A total of 26 locations were selected for the investigation, with groundwater samples collected at three different intervals. Select locations investigating potential source areas were scheduled for the collection of soil samples above the water table. Of the 26 scheduled boring locations, 21 locations were completed with the five remaining boring locations not completed due to denial of access by property owners and/or topography/field conditions encountered (refer to Figure 1).

The soil analytical results for the samples submitted to a laboratory did not indicate the presence of gasoline COCs in soil above regulatory levels with the majority of the data showing non-detectable results for the chemicals analyzed. The groundwater analytical results showed the presence of benzene, TBA and MTBE in groundwater beneath Site #1 and the presence of MTBE immediately down groundwater gradient of Site #2 (access was denied for onsite samples). The detection of benzene, MTBE and TBA and the documented

groundwater gradient flow generally to the east suggest the likely sources of the gasoline COC plume underlying Development #1 are from Site #1 and Site #2, while impact within Development #2, found in June 2004, is likely from Site #2. The background information along with the data collected does not indicate Site #3 to be a source of the impact to the development although the investigation of the area immediately adjacent to the Site #3 could not be completed due to property access denial.

Based on the results of the preliminary investigation activities DNREC-TMB approached the PRPs at Site #1 and Site #2 via letter to request a hydrologic investigation based on the available data instead of continuing the investigation using the State's funding. The monthly management of the POET systems within Development #1 continued to be maintained by DNRECs contractor through State funding.

Alliance, who currently provides consulting services for the Site #1 owner was retained to respond to the DNREC-TMB letter. DNREC-TMB would allow Site #1 to reenter the reimbursement program for the continuation of investigation and subsequent remediation activities due to the uncertainty of whether MtBE was present or not at site closure in 1998, and due to high levels of residual soil contamination.

The owner of Site #2 initially did not respond to DNREC's hydrologic investigation request letter or calls to their offices. After being issued a Notice of Violation (NOV) by DNREC the site owner began to comply with DNREC-TMB requests via an onsite HSA investigation, in the spring of 2005.

**Site# 1 Hydrologic Investigation Activities**

The goals for the hydrologic investigative activities for Site #1are: Obtain the horizontal and vertical delineation of petroleum impact to groundwater (investigation area encompasses locations up gradient of Site #1 through Development #1), determine the link between PRPs and the impact within Development #1, and obtain sufficient data to determine options and costs for the remediation of source area(s) and extent of groundwater impact.

To work toward the goals of the investigation, six cluster monitoring well locations (each location containing five 1-inch diameter PVC wells) were installed in April/May 2004, three cluster monitoring well locations (each location containing four 1-inch diameter PVC wells) were installed onsite Site #1 in August 2004, three delineation cluster monitoring well locations (each location containing five 1-inch diameter PVC wells) were installed in March 2005 and two shallow (< 30 feet bgs) delineation monitoring wells were installed in March 2005. See Figure 1 for location details.

The cluster well locations were installed using the mud-rotary drilling methodology to an estimated maximum depth of 90 feet bgs, which is beyond the depth of the residential well as reported in the available information. The mud-rotary drilling methodology was selected to overcome problems with likely running sands that would complicate drilling activities, elevate investigation costs and compromise analytical data. Soil samples were collected from 50 to 90 feet bgs to confirm geologic material at the initial six cluster well locations.

Individual wells within a well cluster location were constructed from the bottom of the borehole to the ground surface using PVC casing and 0.01-inch slot screen at each of the well cluster locations. The 1-inch wells were secured to a central stabilizer (consisting of either 1.5-inch or 2-inch PVC) with plastic ties and band clamps. Once the wells are set within a cluster location, the borehole was flushed with water to dilute/remove the mud from the borehole. The geologic formation material consisting of mostly sand was allowed to close to form the annulus around the cluster wells and the rest of the well annulus was completed as a typical well with #2 sand, coated bentonite pellets or bentonite chips, cement grout for a surface seal to set a flush mount manhole to complete the cluster well. The individual wells within a cluster were screened from 90 to 85 feet bgs, 75 to 70 feet bgs, 60 to 55 feet bgs, 45 to 40 feet bgs, and 30 to 10 feet bgs, which correspond with the more permeable saturated zones (gravel zones) identified during the drilling activities completed in previous investigations.

Groundwater sampling events have been conducted quarterly since May 2004. A low-flow sampling methodology is utilized for the sampling events to eliminate the draw of water from the other screened intervals within a well cluster. Based on the groundwater data collected during these quarterly events new cluster wells were proposed and approved by DNREC-TMB to meet the investigation objectives.

Maximum concentrations of MtBE detected on Site #1 have been 17,000 ppb in the 10 to 30 foot interval in CW-9. MtBE has also been detected at depth, with higher concentrations detected at sampling intervals greater than 55 feet bg in wells CW-1 and CW-8 as opposed to lower concentrations of MtBE detected in the shallow zones of those two wells. It is likely that this increase is attributed to Site #2's influence and data collected during the investigation of Site #2 will either support or deny the theory.

Due to the detection of a shallow groundwater source area within Site #1 a remediation system is currently in operation (mechanically remote pulsed air sparge soil vapor extraction) as well as the evaluation of a deep remediation barrier system to protect Development #1 from further impact from Site #1 or Site #2.

**Site# 2 Hydrologic Investigation Activities**

In October 2004 seven soil borings were advanced within the property boundaries of Site #2. The borings were located around the perimeter of the property and near the existing UST system. Both soil and groundwater samples were collected from the borings to a maximum depth of 40.5 feet bgs. Groundwater analytical results indicated a maximum concentration of 380,000 ppb of MtBE at 22 feet bg and 16,000 ppb of MtBE at 40 feet bgs. Groundwater flow direction was determined to be towards the southeast with a component of flow to the west and south.

A report documenting the activities was submitted to DNREC-TMB in December 2004. In January 2005, DNREC-TMB requested both onsite and offsite investigations with permanent wells at depth to correlate with the potable wells in the area. The request also included deadlines for: abatement measures for the MtBE detected, UST system testing and the

transfer of monthly monitoring and POET maintenance for Development #2 to the PRP of Site #2. A work plan for an onsite investigation was submitted in February 2005 and approved by DNREC-TMB in March 2005. The approval was accompanied with a request from DNREC-TMB for additional and deeper monitoring wells. DNREC-TMB is awaiting work plans and reports for the offsite investigation, abatement measures and UST system testing required to be completed by Site #2 PRP.

The proper assessment and remediation of source areas identified at Site #2 is essential in the abatement of the potable well impact in Development #2. With the proximity of the agriculture well to Site #2 a link to Development #1 impact is likely and is supported by the detection of MtBE in the deep groundwater (>55 feet bgs) documented up gradient of Site #1.

**Site #1 Remedial Feasibility Testing**

Due to the geology (mostly sand) and depth to water at the site (> 15 feet bg), air sparge/soil vapor extraction was considered to aggressively remediate source soils and shallow groundwater (<35'). In order to determine the feasibility of an air sparge/soil vapor extraction (AS/SVE) system an AS/SVE pilot test was completed in May 2005.

A SVE pilot test point was installed to approximately 20' below grade (bgs) and screened from 5 to 20' bgs. An AS pilot test point was installed to 35' bg and screened from 30 to 35' bg. Monitoring points with similar construction were installed to record parameters such as vacuum/pressure influence, airflow rates, dissolved oxygen, and depth to water in order to evaluate the applicability and effectiveness of this type of remedial option. The AS/SVE pilot test was conducted in the vicinity of CW-9. Please refer to Figure 1.

In order to address impacted groundwater at depths greater than 35' bgs, additional pilot testing was completed to evaluate the feasibility of remedial technologies such as ozone injection, pulse air sparging or oxygen diffusion. Air sparging at depth should also aid in limiting the downward MtBE and benzene migration due to the upward flow and pressure of injected air.

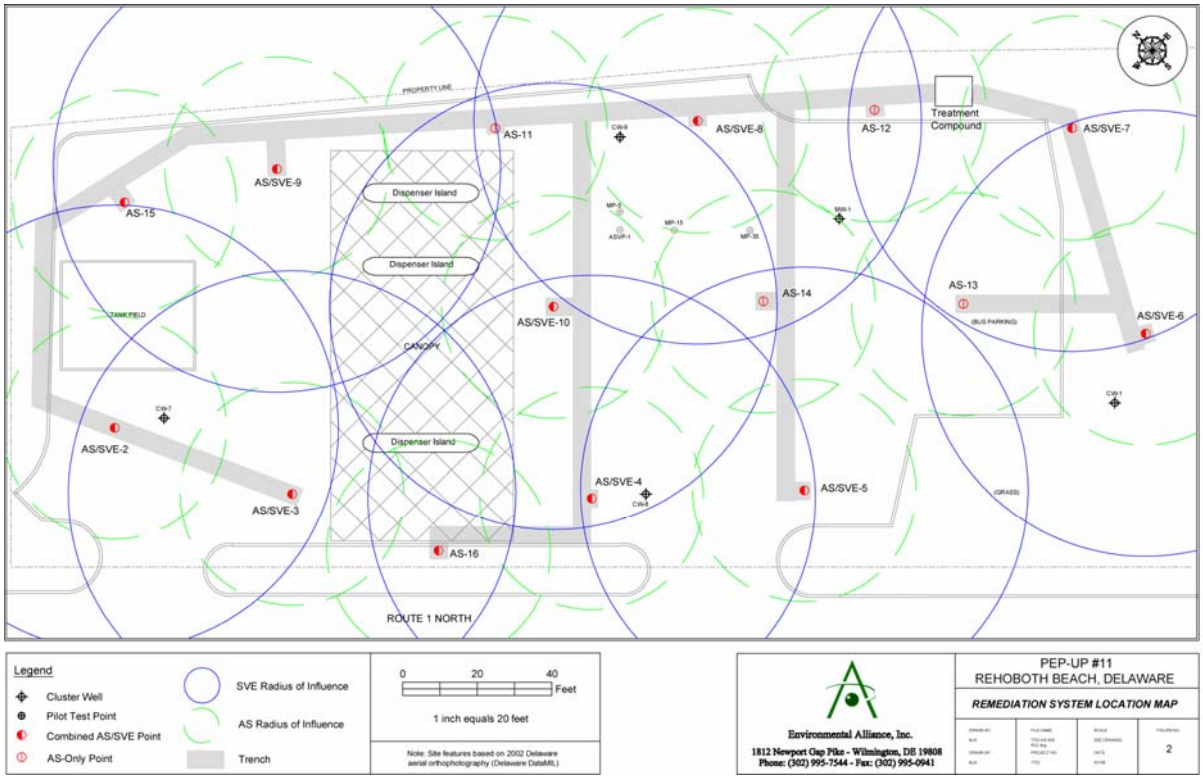
The additional pilot testing consisted of injecting air at lower flow rates (< 3 scfm) than the air sparging pilot test and at greater depths (screened intervals of 50 to 55 ft bgs and 70 to 75 ft bgs). Monitoring points with similar construction were utilized to record parameters such as pressure influence, dissolved oxygen, depth to water, ORP, and conductivity/resistivity in order to evaluate the applicability and effectiveness of these types of remedial options.

Biological data such as iron, sulfite, BOD, COD, total aerobic bacteria, total aerobic degrader bacteria, TOC, nitrate/nitrite, pH, etc. was collected in August 2004 from CW-1 (10-30' and 55-60'), CW-3 (55-60'), and CW-4 (55-60') representing locations that are in the heart of the contaminant plume (Site #1 area), side gradient of the plume and at the toe of the plume, respectively. The data indicates that there is a very healthy and vigorous aerobic bacteria population in all three monitoring wells, particularly at CW-4 with $8.1 \times 10^6$ cfu/ml. The only location that has indicated a severely limited number of aerobic bacteria is the CW-1E

at the top of the groundwater aquifer in the heart of the plume with only 1.9 x $10^4$. This may be a result of the toxicity of the contaminants at that elevated level to the bacterial populations. CW-4 also exhibited the largest number of total aerobic degrading bacteria as well with 1 x $10^5$ cfu/ml. This data is typical of degrading bacteria at the leading edge of a plume that has had time to slowly acclimate to the contaminants as a food source. The geochemistry data collected at all three points indicate very low bio-available nutrients (nitrogen and phosphorus) and low TOC. These are essential for dynamic bacterial population growth and contaminant degradation. The relatively low pH (range of 5.4 to 6.3 pH units) may be limiting bacterial degradation as well.

**Site #1 Shallow Source Zone Remediation**

Subsurface piping to the sixteen air sparge (AS) and ten soil vapor extraction (SVE) points was completed in November 2005, refer to Figure 2. Before startup an Underground Injection Control (UIC) Rule Authorization number and an air permit exemption for operation of SVE with catalytic oxidation and/or carbon adsorbtion air pollution control devices was obtained from DNREC.




With the appropriate permits obtained to operate an AS/SVE system at the site, Alliance personal mobilized a portable remediation trailer capable of producing 100 to 150 scfm of air at 9 psi for injection (AS) and 244 scfm of soil vapor at a vacuum of 42"$H_2O$ (SVE). Alliance added remote monitoring capabilities to the system. Utilizing a cellular connection Alliance has the ability to remotely adjust flows through a program logic control (PLC) system, pressure/vacuum transmitters and solenoid valves. The PLC can also monitor the temperature across the catalytic oxidizer to evaluate the rate of contaminate oxidation. The

remote monitoring capabilities will also limit the need for frequent site O&M visits in the future.

Within the PLC the air sparge blower can be programmed for a pulse operation of the blower. The catalytic oxidizer was sized to handle the SVE flow rate (Falco 300). The process equipment will include a moisture knock out tank to separate entrained water in the soil vapor intake. The process also contains three interlocks for process control. The first monitors the water knockout tank for high water level. If the high water level tank probe reaches alarm, the soil vapor system will automatically be shut off. The second interlock monitors the vacuum on the soil vent system. If the vacuum drops to near zero, indicating that the soil vapor system has been shut off or is malfunctioning, then the air sparge system will be shut down. This is an important consideration since one must always ensure that air sparging occurs concurrently with soil vapor extraction. In this way, the air sparging vapors will always be controlled. The third interlock monitors the operation of the catalytic oxidizer and shut off the soil vent system if the unit fails.

Startup of the SVE system was April 12, 2006 and frequent site visits were made during the first few months of operation for system monitoring, adjustments, and troubleshooting repairs. During each site visit, the flow rate of each soil vapor extraction point was monitored, the hydrocarbon concentration in the vapor extracted from each point was monitored using a PID, and the total process conditions were monitored (flow rate, concentration, and vacuum) on the SVE system. Temperature readings were recorded pre-, post-, and mid-catalyst locations on the Falco 300. Once the sparge system was started (May 31, 2006), site visits included individual and combined flow measurements and pressure readings from the sparge points. In addition, monthly monitoring of depth-to-water, dissolved oxygen, and pressure measurements at the well heads is completed with Tedlar™ air bag samples from the influent and effluent air stream to the CatOx collected on a monthly basis.

As of October 1, 2006, approximately 13,000 pounds of vapor phase hydrocarbons have been extracted from the vadose zone. Since start-up the combined extracted soil gas flow rate from the SVE points has been approximately 100 CFM. The influent air flow rate to the Cat/Ox (made up of extracted soil gas and dilution air) has been on average approximately 240 CFM with PID readings ranging from 138 ppmv (PID units) to 591 ppmv. The greatest petroleum vapor concentrations, as recorded with a PID, have been from point SVE-9 which is located east of the tank field.

As soil vapor concentrations decline the air sparge of the system will be put into pulse mode and as mass extraction rates continue to decline the cat/ox will be replace with vapor phase carbon. It is anticipated that an addition twelve months of operation will be required to meet the remedial goals for Site # 1.

## Development #1 Connection to Public Water

During the fall of 2005 DNREC-TMB, through its contractor, began to connect thirty-five residents to public water by expending an existing supply line into Development #1. All connections were completed by February 2006. The residents that were connected to public water were within and surrounding the area of impact (14 domestic wells) within Development #1. Through groundwater monitoring the need for groundwater containment and remediation is being evaluated. With the discontinuation of pumping from the 35 closest domestic wells to Site #1 and Site #2 the groundwater velocity within the formation has slowed which may allow natural attenuation to limit further domestic well impact.

## Future Plan

A phased remedial strategy is being completed for the study area. Air sparge/soil vapor extraction is aggressively remediating source soils and shallow groundwater for Site #1. Future remedial options of ozone injection, pulse air sparging, and/or oxygen diffusion is being evaluated to remediate the deeper groundwater zones and impacted groundwater moving through the deeper zone from the Site #2 source area. The potential need for this is due to potable well impact within Development #1 and the numerous withdraw points down gradient of Development #1. The current evaluation of a stable and/or shrinking contaminate plume through monitoring needs to be completed to justify the costs and need associated with this deep groundwater zone remediation. If required, groundwater extraction using the former potable wells (properties that have been connected to public water) as pumping wells will limit further plume migration and maintain the groundwater gradient and velocity for movement through the proposed treatment areas.

The project is complicated without the proper assessment and remediation of the identified upgradient source on Site #2. Future remediation costs and duration for the possible deep treatment zones, groundwater containment and monitoring within Development #1 cannot be determined.

## References

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## Biographical Sketches

**Joseph A. Zay III** has been an Environment Scientist with Environmental Alliance, Inc. since 1995 and has over 11 years of work experience in the engineering and environmental consulting industry. He is currently Vice President of Field Operations and manages all field operations that include site investigation and remediation projects from large industrial facilities to retail gasoline stations. Principally his responsibility and lies with petroleum projects conducted under state oversight from Connecticut through Virginia. Joseph holds a B.S. in Physical Geography - Pennsylvania State University.

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