Evaluation of the Hydrologic Effects of Oxygen Injection for Biostimulation in an Upper Glacial Aquifer on Long Island

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Oxygen injection technology is being successfully implemented to increase aerobic biological activity and significantly reduce concentrations at the toe of an approximately 3,400 foot long groundwater plume emanating from a former manufactured gas plant (MGP) site. The interim remedial measure (IRM) was designed to reduce concentrations within the plume prior to discharge into a tidally influenced tributary of the Great South Bay while a source removal and containment remedy was implemented. This study was conducted to evaluate the potential for O2 injection to alter groundwater flow conditions in the vicinity of the injection wells.

The success of the IRM promoted additional interest for expansion of the technology to other areas of the plume. However, increases in concentrations of volatile organic compounds and polycyclic aromatic hydrocarbons in groundwater outside of the original plume boundary raised concerns that the oxygen injection may be inadvertently diverting the groundwater plume beyond the limits of the treatment zone. A joint study was undertaken by National Grid, the New York State Department of Environmental Conservation, and Suffolk County Department of Health Services to address these concerns. The study included a review of existing physical groundwater parameter data and treatment system operational data; collection of continuous water level measurements over a fourteen day period in forty-eight monitoring wells; and the collection and chemical analysis of soil, groundwater, and soil vapor samples from the treatment zone. Groundwater and soil vapor samples were collected over two periods: normal system operations and following a five day period when the system was taken out of operation. A comparison of the data for each system condition, as well as a comparison to historic performance and monitoring data, is evaluated and presented. The study concluded that the oxygen injection did not alter groundwater flow conditions in the vicinity of the injection wells.

1. Introduction

This report presents the results of a hydrologic study conducted to further evaluate the groundwater conditions in the vicinity of an oxygen injection system installed in Operable Unit No. 2 (OU-2) of the Bay Shore/Brightwaters former Manufactured Gas Plant (MGP) site. Concerns arose that the oxygen injection line located at Garner and Manatuck Lanes (herein referred to as “the Manatuck injection line”) might be inadvertently deflecting the groundwater plume beyond the limits of the treatment zone. This concern was based on an apparent increase in contaminant levels in groundwater samples collected from a Suffolk

County Department of Heath Services (SCDHS) monitoring well cluster after the injection began.

A joint study was undertaken by National Grid, NYSDEC, and SCDHS to address these concerns. National Grid implemented the field program under both NYSDEC and SCDHS oversight between May 29, 2007 and July 26, 2007.

The study included the following site activities:

- Installation of soil borings, temporary groundwater probes, and additional monitoring wells;
- Collection and chemical analysis of soil, groundwater, and soil vapor samples;
- Evaluation of the groundwater elevations near the injection lines while the oxygen injection system was operating versus shut down;
- Evaluation of the chemical extent of MGP-related constituents in groundwater while the oxygen injection system was operating versus shut down; and,
- Evaluation of soil vapor concentrations in the vicinity of the oxygen injection system while the system was operating versus shut down;
- Evaluation of the potential contribution of other petroleum releases adjacent to the oxygen injection system.

1.1 Site History and Description

The Bay Shore MGP began operations in the late 1880s on the Operable Unit No. 1 (OU-1) parcel. The plant was operated by Mutual Gas and Light Company, The Suffolk Gas and Electric Light Company, and later the Long Island Lighting Company (LILCO) in 1918. LILCO operated the plant from 1918 to approximately 1973 when most of the facilities were demolished. In 1998, KeySpan Corporation acquired the former MGP property through a merger of LILCO and Brooklyn Union Gas Company. In 2007, National Grid acquired the former MGP property through a purchase of KeySpan Corporation.

OU-2 includes a mixture of residential and light commercial properties. The OU-2 dissolved-phase groundwater plume appears to migrate south to southeast from OU-1 in the direction of local groundwater flow. The Remedial Investigation (RI) and subsequent groundwater sampling events have bounded the width of the plume to an approximate 500-foot wide path extending from OU-1 and the southeast corner of the Bay Shore West Parcel. The boundary of the plume was based on concentration isopleths for total polycyclic aromatic hydrocarbons (PAH) and total Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX) greater than 100 micrograms per liter (ug/L). The total length of the plume is estimated to be approximately 3,400 feet extending from OU-1 to the discharge point at Lawrence Creek.

Lawrence Creek, a tidally influenced tributary of the Great South Bay, is located south of Montauk Highway. Although the plume discharges to Lawrence Creek, analysis of surface water and sediment samples collected from the suspected discharge area during the RI indicated BTEX and PAHs to be at relatively low concentrations. Impact to the underlying Magothy aquifer is not expected. While the groundwater plume immediately downgradient of OU-1 appears to extend throughout the vertical profile of the Upper Glacial aquifer, the low permeability fine sands, silt, and clay underlying this aquifer restricts the downward migration of the plume. The downward migration of the plume is further limited by the transition from a predominantly horizontal flow regime to an upward or discharging flow regime in the Upper Glacial aquifer as the plume approaches the natural discharge point of Lawrence Creek.

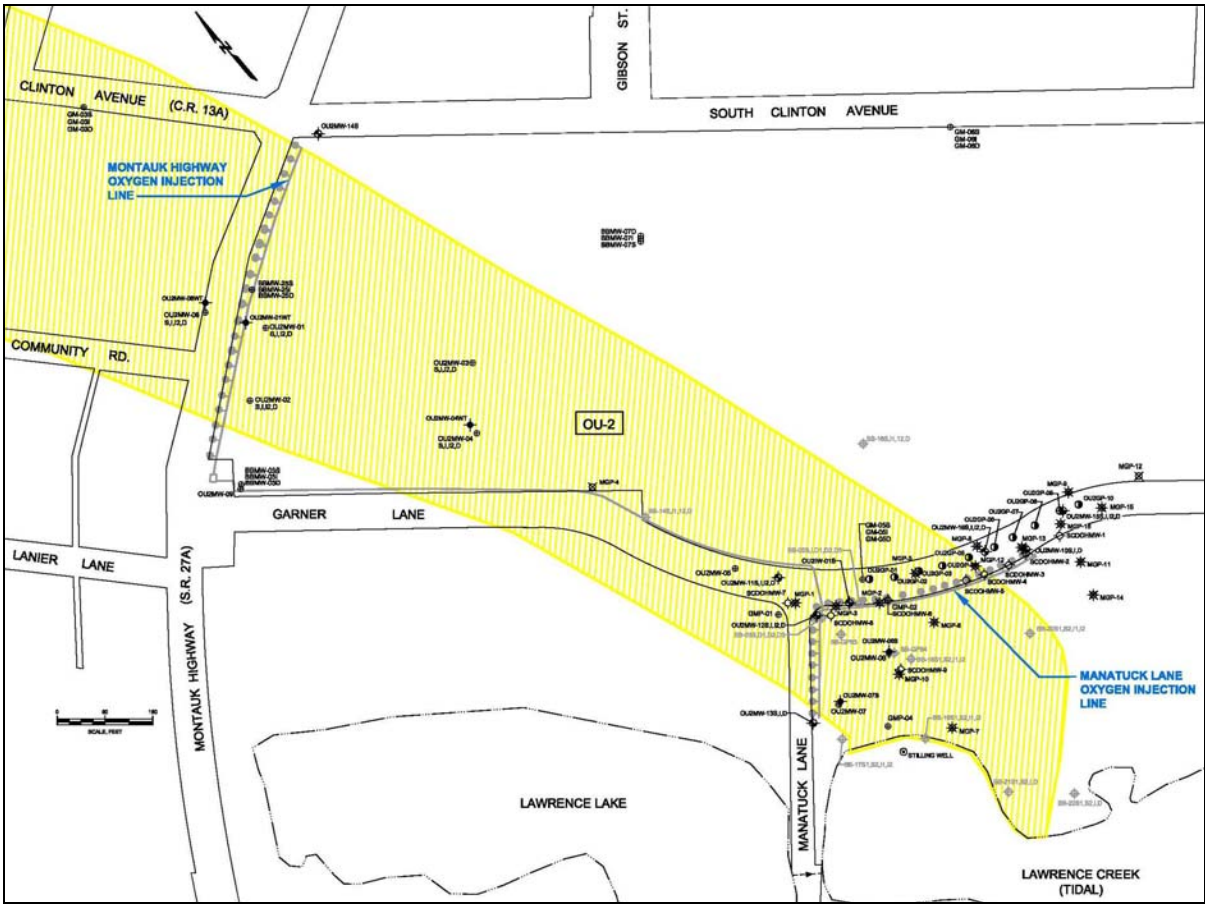


Figure 1: OU-2 Study Area

2. Oxygen Injection System Technology Description

The oxygen injection system at OU-2 was installed as an interim remedial measure (IRM) to reduce the concentrations of volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) in the OU-2 groundwater plume while remediation of the source (OU 1) was designed and implemented. Remediation activities are ongoing at OU-1 to remove and contain the source of the VOCs and SVOCs to the groundwater plume.

The system consists of a rotary screw air compressor, refrigerated air dryer, pressure-swing adsorption oxygen generator and automated oxygen delivery manifold. Ambient air is compressed to 110 pounds per square inch (PSI) and conditioned through a series of filters and the air dryer. The compressed air flows to an oxygen generator where the nitrogen is removed through a process called pressure swing adsorption. This process uses a molecular sieve (synthetic zeolite) which adsorbs nitrogen at high pressure and releases it at low pressure. The resulting gas stream with an oxygen purity of 90 to 95 percent is stored in a receiver tank for injection into the aquifer. This process of generating oxygen gas produces no waste other than nitrogen which is inert and purged to the atmosphere. It is also a safe and reliable process that does not require special handling as with high pressure oxygen cylinders, liquid oxygen or hydrogen peroxide. The equipment is contained in an insulated cargo trailer and includes sound dampening, heating, ventilation and electrical controls.

Oxygen gas is injected into groundwater to increase the dissolved oxygen concentration and enhance aerobic biodegradation of BTEX and naphthalene. The oxygen gas is injected in pulsed intervals into the subsurface through a series of injection wells at low flow rates. The low flow rates and pulsed injection intervals are intended to allow for the maximum transfer of vapor-phase oxygen to dissolved-phase oxygen though dispersion into saturated soils. The injection wells are set in drilled borings and consist of PVC pipe which is slotted at the bottom and surrounded by a sand filter pack. Hydrated bentonite is used to create a seal above the filter pack to prevent the injected gas from travelling upwards through the boring. Each injection well is connected to the oxygen injection system with high density polyethylene tubing. An oxygen injection cycle begins by displacing water from the injection well followed by oxygen flow through the slotted PVC and filter pack. The filter pack acts as a diffuser by creating small bubbles of oxygen gas which disperse into the surrounding formation due to a pressure differential. A schematic showing the general process flow is shown in Figure 2.

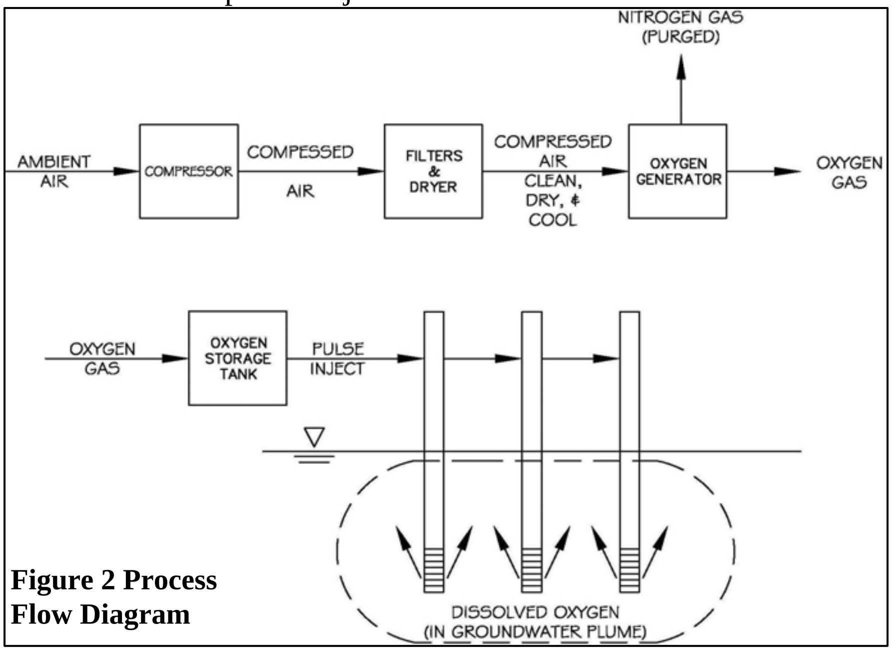


Figure 2 Process Flow Diagram

Unlike air sparging, the goal of oxygen injection is to transfer the injected vapor to the aqueous phase. The goal of air sparging is to maintain the injected vapors in the vapor phase where they can strip the VOCs, such as BTEX, from the groundwater for collection in the vadose zone and subsequent treatment. Injecting oxygen at 90 to 95 percent purity can increase dissolved oxygen concentrations to a maximum of approximately 40 milligrams per liter (mg/L), whereas air injection yields a maximum dissolved oxygen concentrations of approximately 9 mg/L. The injected oxygen in the dissolved-phase is used by indigenous microorganisms to aerobically degrade the organic chemicals. The injection of oxygen leads to the formation of an aerobically active treatment zone at the injection wells where groundwater passing through the zone is oxygenated and aerobic microbes in the groundwater use the increased dissolved oxygen to biodegrade the dissolved-phase contaminants of concern (COCs). This method of producing oxygen gas on-site and injecting into groundwater at high transfer efficiencies to stimulate biodegradation is described in U.S. Patent No. 5,874,001.

The system is divided into six injection banks of seven to ten injection points. Injection banks 1 through 3 (IB1, IB2, IB3) are located in the Montauk Highway injection line and injection banks 4 through 6 (IB4, IB5, IB6) are located in the Manatuck Lane injection line. Each injection bank consists of seven to ten injection wells. The oxygen flow rate is controlled to each of the wells with flow meters with a range of 10 to 100 standard cubic feet per hour (SCFH). The flow meters are adjusted to account for changes in the water table elevation and are typically operated at 30 SCFH. Twenty-four hour timers are set to restrict the injection of oxygen to approximately 16 minutes per hour in one injection bank at a time. Following the injection period, the oxygen generator recharges the oxygen tanks for approximately 44 minutes. No oxygen injection occurs during this 44-minute period. At the completion of the 44 minutes of recharge, the system shifts to the next injection bank, oxygen is injected for approximately 16 minutes, and the cycle repeats. In this manner, oxygen is injected four times per day at each injection bank (seven to ten wells) for approximately 16 minutes each injection period, and the injection periods for each injection bank are separated by approximately 5 hours and 44 minutes. The accuracy of the twenty-four hour timers is +/- 360 seconds (6 minutes). During field implementation of the **study**, the actual duration of injection at each bank ranged from 16 to 22 minutes and was within the equipment limitations. The average injection duration of approximately 20 minutes was used in data evaluation. At this duration and oxygen flow rate of 30 SCFH, approximately 2.5 to 3 lbs of oxygen gas were injected into each injection well per day.

To date, the IRM at OU-2 has been successful in reducing groundwater concentrations at and downgradient of the injection lines (GEI, 2008).

3. Field Activities

3.1 Investigation Activities

Baseline (pre-study) groundwater data used for comparison were obtained from the quarterly OM&M groundwater sampling database. Quarterly OM&M soil vapor sampling data was used to establish a baseline of soil vapor conditions prior to the start of the study and two months after completion of the study.

The following samples were collected from each of these investigation points.

- Twenty-eight subsurface-soil samples were collected from 4 boring locations.
- Eighty groundwater samples were collected from 10 temporary groundwater probes.
- Ninety groundwater samples were collected from 65 monitoring wells.

- Eighteen soil vapor samples were collected from 11 permanent soil vapor points. An additional eleven samples were collected two months after the work was completed as part of the Quarterly OM&M sampling.

3.2 Groundwater Elevation Data Collection

A total of 48 wells were equipped with data logging pressure transducers (Mini-Trolls® or Troll 9500s®) to record groundwater elevations within the wells. These wells included wells at the groundwater table and at greater depths near the oxygen injection lines. Data were collected for a one-week period while the oxygen injection system was in operation and a one-week period while the system was off-line. During each period, weather data were collected to identify any significant events that may influence the groundwater levels or the surface barometric pressures.

The Trolls were downloaded periodically during the study at intervals of approximately 2-days to ensure that no more than 2 days of data could be lost if a Troll malfunctioned during the study. At the time of the download, the groundwater levels were also manually measured seven times during the study.

3.3 Groundwater Elevation Data Evaluation

Following the completion of the study, the raw pressure data collected from the Trolls were used to calculate the groundwater table elevation in each well. At the beginning of the study, each Troll registered the existing conditions as the zero (0) level surface for the individual monitoring well. The initial manual groundwater level measurements were made shortly after the beginning of the study. The “Level Surface” or “Pressure” value of the Troll at the exact time of the manual measurement was used as the reference value for the monitoring well.

Hydrographs of the groundwater elevation data calculated at each well were plotted to identify any irregularities in the calculated data. Irregularities were limited to sudden drastic shifts in groundwater elevations that either did not appear consistent with the remaining data or the manual measurements collected during the study. Irregularities related to precipitation events were observed in each well. Two significant rain events contributed to groundwater table elevation increases during the second week of the study. In each non-weather related case, the sudden drastic shifts in groundwater elevation fell into four categories:

- Sudden increases/decreases which returned to the “normal” elevation immediately;
- Sudden increases/decreases which remained at the altered elevation for a short period of time and then returned to the “normal” elevation;
- Sudden increases/decreases which remained at the altered elevation for the remainder of the study; or,
- Continued increases/decreases over a prolonged period of the study.

The date and time of each irregularity was compared to the monitoring well/Troll log sheet to determine if human error may have contributed. Human error included accidental movement of the Trolls during periodic downloading, during manual groundwater level measurements, or during groundwater sampling during the second week of the study.

For each irregularity identified, the data was normalized based on the following procedures.

- For sudden increases/decreases that returned to the "normal" elevation immediately, the data points which caused the spike or dip in the hydrographs were removed if human error was a contributing cause. An average of the data points on either side of the spike/dip was used to replace the deleted data points.
- For sudden increases/decreases that remained at the altered elevation for a short period of time and then returned to the "normal" elevation, the data were compared to the manual water level elevations. If human error contributed to the change, then a correction factor was applied to the data for the period effected based on the manual groundwater elevation measurements.
- For sudden increases/decreases that remained at the altered elevation for the remainder of the study, the data were compared to the manual water level elevations. If human error contributed to the change, then a correction factor was applied to all data after the sudden increase/decrease based on the manual groundwater elevation measurements.
- For continued increases/decreases over a prolonged period of the study, the data were compared to the manual water level elevations. If instrument drift appeared to contribute to the change, then correction factors were applied for all data based instrument drift calculated between each set of manual measurements.

3.4 Groundwater Analytical Sampling

Two rounds of groundwater monitoring and sampling was conducted for the study area wells. The first round corresponded to the quarterly monitoring sampling conducted for the site-wide OM&M. All groundwater analytical samples were collected and analyzed for VOCs via EPA method 8260B and PAHs via EPA method 8270B. Select samples were also analyzed for Standard Plate Count.

The second round of groundwater sampling was conducted during the last two days of the second week of the study while the system was off line. Twenty-two of the sixty-five monitoring wells were sampled for the parameters identified above. Since the groundwater flow rates in the study area are approximately 1 to 2 feet per day, the selected wells were those located within approximately 20 feet of the injection lines, or those specifically requested by the NYSDEC or SCDHS. In general, the selected wells were those located up- and downgradient of the injection lines to identify any significant changes in groundwater COC concentrations following the system shutdown.

3.5 Subsurface Soil Analytical Sampling

Four soil borings were advanced at the location of four monitoring wells to identify any potential impacted soil in the vicinity of the injection lines. Soil borings were advanced at the locations of monitoring wells clusters OU2MW-11, OU2MW-12, OU2MW-15 and

OU2MW-16. At each location, continuous geoprobe macro-cores were collected and logged from the ground surface to the 40 feet below grade. All subsurface soil samples were analyzed for VOCs via EPA method 8260B and PAHs via EPA method 8270B.

3.6 Soil Vapor Analytical Sampling

Soil vapor samples have been collected from permanent soil vapor points on a quarterly basis (GEI, 2007). The Q2 2007 monitoring event was conducted between the end of May 2007 and the middle of June 2007. All permanent soil vapor points were sampled prior to the start of the study as part of the Q2 2007 sampling event. A second round of sampling was performed at the points located near the treatment system injection lines at the end of the second week of the study. After the completion of the test, all permanent soil vapor points were sampled as part of the Q3 2007 sampling event at the end of August 2007.

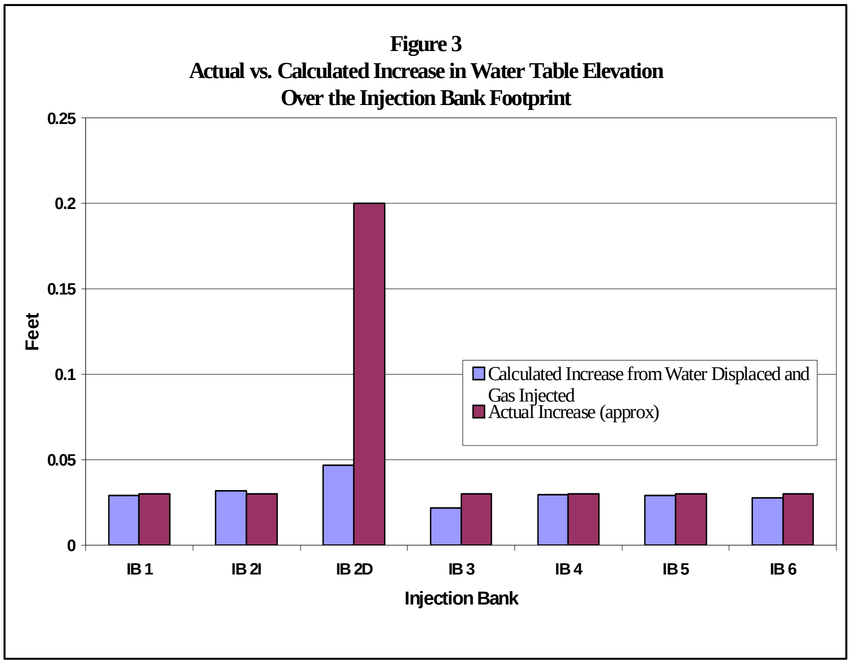
4. Study Results

4.1 Groundwater Elevation Study

For each of the 48 monitoring wells, a hydrograph was created using the groundwater elevation data plotted over the length of the study. The individual well hydrographs are included in Appendix A. Subsets of the data over two two-day periods are also provided for each well. This includes two days during the first week while the system was operating and two days while the system was off line. On each hydrograph, the groundwater elevations are compared to both the surface water elevations in the stilling well, representing the tidal conditions, and the injection durations of the three injection banks of the closest injection line.

No variations in groundwater flow direction were observed as the system's injection banks cycled normally during the first week of the study. As expected, a slight increase (<0.03 feet or <0.36 inches) was observed in water levels in monitoring wells near the injection lines during injections. As discussed in Section 2, oxygen is injected in each well at the minimum breakthrough pressure required to displace the water column in the injection well so that the injected oxygen gas is transmitted into the aquifer. During this process, the water column in the well and the injected oxygen gas is injected into the aquifer and results in a localized increase in the groundwater table at and near the point of injection.

The predicted change in the groundwater table, based on the volume of water displaced and gas injected over the radius of influence of the wells was calculated and compared to the actual change in the closest monitoring wells. The predicted change matched the actual change in all locations except for the deep injection wells at IB2. In two deep monitoring well locations at IB2, OU2MW-08D and OU2MW-12D, the increases were slightly larger during injection (approximately 0.2 feet or 2.4 inches and 0.12 feet or 1.44 inches respectively) than predicted. These wells are screened at or near the surface of the Magothy formation. As noted during prior investigations in OU-1, the surface of the Magothy formation varies widely and may result in localized variations in groundwater flow at or near the surface (GEI, 2005, D&B, 2003). The variations in the surface topography of the Magothy formation and variation of the permeability of the material at/near the top Magothy formation may account for the hydraulic response variations observed in the two deep wells at this location.



In all cases, the increases are limited to the wells closest to the injection lines and do not propagate far from the point of injection. For all wells, the observed increases are transient and dissipate almost immediately after the injection ceases. In the case of the two deeper wells, the larger increases do not appear to affect the groundwater increases observed in the intermediate and shallow wells in these clusters. This indicates that the effects of the injection are limited to the groundwater at the depth intervals of the injection wells and the injected oxygen is dissolving into groundwater in the deeper portion of the aquifer.

Water table groundwater contours maps were created to evaluate whether the slight increases observed during injections affect the overall groundwater flow directions in OU 2. A series of contour maps were generated to depict the piezometric surface at time periods 30 minutes prior to the injection at each injection bank, during injection, and 30 minutes after injection. These groundwater contours were then compared to the groundwater contours during the same tidal period during the week when the system was off-line. A typical set of these contours is presented below (Figure 4) for the eastern edge of the Manatuck Lane injection line (IB6) where the increased concentrations in the SCDHS monitoring wells prompted the study.

There is no variation in the groundwater flow direction at any location during the first week of the study while the system was in operation, demonstrating that operation of the oxygen injection system is not affecting the groundwater flow directions. Minor variations between the contours while the system was in operation vs. the groundwater contours while the system was off-line are the result of precipitation events and are not related to the operation of the oxygen injection system. These minor variations relate to two significant rainfall events (3.09-in over a 2-hour period on 7/18/07 and 0.92 in over a 9-hour period on 7/23/07) that occurred during the second week of the study and significantly effected groundwater elevations. After the July 18th rainfall event, groundwater elevations increased approximately 0.3 feet and were still decreasing to pre-rainfall event levels when the July 23rd rainfall event caused an additional increase of approximately 0.1 feet. The groundwater elevations did not return to the pre-July 18th rainfall event levels during the duration of the study.

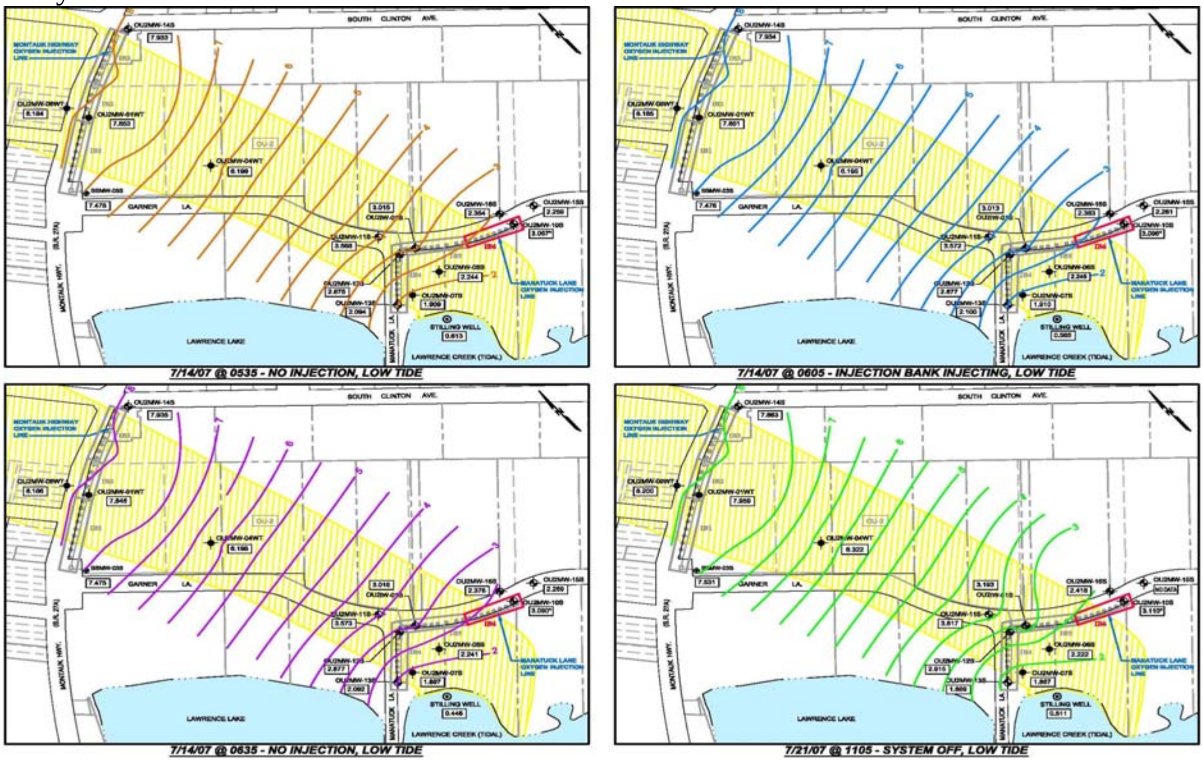


Figure 4 Groundwater Elevation Contours (IB6)

4.2 Groundwater Analytical Results

A comparison of the analytical results of groundwater samples collected before the start of the study and during the last days of the study when the system was off-line was conducted. There were no significant variations in total BTEX or total PAH concentrations from samples collected while the system was in operation or when the system was off-line.

The total BTEX concentrations and total PAHs concentrations from the samples were compared to the previously-identified 100 ug/L edge of the OU-2 groundwater plume. At each of the wells clusters located at the edges of the injection lines, the total BTEX and total PAH concentrations were non-detect or below 100 ug/L total BTEX and total PAHs.

Diffusion of oxygen into the groundwater is occurring within the aquifer. The concentrations of dissolved oxygen (DO) at and near the injection points have increased from 0 mg/L to up to 40 mg/L. The high DO concentrations are evidence that oxygen gas is diffusing into the aquifer. IB 2 includes injection well couplets injecting at 23 and 63 feet below grade. Monitoring wells clusters adjacent to these wells have been monitored for dissolved oxygen during routine sampling. At the BBMW-25 cluster, as expected, high DO concentrations are observed at or above the depth of injection.

Monitoring/Injection Well	Screen Interval	Q3 2007 Dissolved Oxygen
BBMW-25S	4 to 14 feet below ground surface (bgs)	34 mg/L
Injection Points 15, 17, 19	Injection depth 23 to 24 feet bgs	
BBMW-25I	25 to 35 feet bgs	17.66 mg/L
Injection Points 16, 20	Injection depth 48 to 49 feet bgs	
BBMW-25D	62 to 72 feet bgs	30 mg/L
Injection Point 18	Injection depth 64 to 65 feet bgs	

4.3 Subsurface Soil Analytical Results

There were no detections of BTEX or PAHs in any of the samples collected.

4.4 Soil Vapor

The fate and transport of soil vapor in the subsurface is dependent on various chemical and environmental conditions that directly affect the concentrations detected (United States Environmental Protection Agency [EPA], 1997, NYSDOH, 2006). These include the vapor pressure and the Henry's law constant of the individual COCs present, the temperature and barometric pressure at the surface, and the moisture content and porosity of the vadose zone soils. In addition, several other soil factors can influence the distribution of COCs in the soil vapor. Preferential pathways such as sub-surface utilities, tree roots, and backfilled areas can allow vapor migration away from a source area. Conversely, impervious zones or layers such as clay/peat/ organic soil layers, foundations, buried structures, or perched groundwater can trap or inhibit the flow of soil vapors.

Eleven soil vapor locations were sampled before the study as part of the Q2 2007 OM&M sampling event and seven were re-sampled during the last days of the study while the system was off-line. In addition to the eleven points located in the study area, four additional samples were collected from other areas within OU-2, OU-3 and on the southwest side of Lawrence Lake outside of the influence of the groundwater plume as part of the site wide OM&M sampling in Q2 and Q3 2007. The analytical results from the study were also compared to the historical concentrations of soil vapor from each sample point beginning in May 2005 (GEI, 2006).

Soil vapor concentrations have varied widely between 2005 and 2007 at all locations monitored. The variations in concentrations have occurred both before the system was installed and after the system was in operation. Decreases in soil vapor concentrations at or downgradient of the injection lines, specifically between the April/May/June 2007 sampling events and Week 2 sampling event during the system shutdown portion of the study, are not the result of system operation and the subsequent system shutdown. These same decreases are observed in soil vapor samples collected from points upgradient of the injection lines and on southwestern side of Lawrence Lake outside of the influence of the groundwater plume and the injection systems. The soil vapor concentration fluctuations occur throughout the Bay Shore/Brightwaters community, regardless of system operation. Therefore, it is likely that a combination of the chemical and environmental factors discussed above is effecting soil vapor concentrations and there is no evidence to support that operation of the oxygen injection system adversely effects soil vapor concentrations.

4.5 Evaluation of Other Contributing Sources

Increases in VOC and SVOC concentrations were noted in SCDHS monitoring well MGP-11 between the November 2004 and January 2007 sampling events. The location of this well raised concerns that the plume might have deflected around the end of the treatment zone. However, a review of the NYSDEC spills database also revealed the existence of two separate open fuel oil spills in a nearby residence, upgradient from this location, during the same time interval. The study included and assessment to determine the potential contribution of these spills or any other non-MGP related sources to contribute to the plume in this area.

A series of 10 groundwater probes were installed along the eastern side of Garner Lane opposite the edge of the Manatuck Lane injection line. Discrete groundwater samples were collected from these probes at the water table and at 5-foot intervals to a maximum depth of 40 feet below grade. A sharp decline in total BTEX and total PAH concentrations was identified from OU2GP-01 located within the identified plume to OU2GP-05 located outside the edge of the plume. Similarly, there is a sharp increase in BTEX and PAH concentrations observed between OU2GP-08 and OU2GP-09 outside of the defined plume limits. Two permanent monitoring well clusters, OU2MW-15 and OU2MW-16 were installed in the vicinity of the groundwater probes OU2GP-05/OU2GP-06 and OU2GP-09, respectively. The concentrations observed in these wells were consistent with the findings of the temporary groundwater probes.

The vertical head potential was calculated at both well clusters, OU2MW-15 and OU2MW-16 to determine the potential for vertical migration of the impacts in this area. The vertical head potential is the measure of the potential for vertical groundwater flow in a porous medium based on the difference in hydraulic head in the well and is calculated as follows:

$$Vertical\_Head\_Potential = \frac{Difference\_in\_Hydraluic\_Head}{Vertical\_Distance\_Between\_Midpoint\_of\_Screened\_Intervals}$$

Monitoring Well IDs (Mid Point of Screen Interval)	Vertical Head Potential (ft/ft)	Direction
Deep Interval to Intermediate 2 Interval		
OU2MW-15D (42.5 ft) & OU2MW-15I2 (32.5 ft)	0.0229	Upward
OU2MW-16D (37.5 ft) & OU2MW-16I2 (22.5.5 ft)	0.0142	Upward
Intermediate 2 Interval to Intermediate Interval		
OU2MW-15I2 (32.5 ft) & OU2MW-15I (22.5 ft)	-0.0037	Downward
OU2MW-16I2 (22.5.5 ft) & OU2MW-16I (17.5 ft)	0.0312	Upward
Intermediate Interval to Shallow Interval		
OU2MW-15I (22.5 ft) & OU2MW-15S (5.5 ft)	0.0076	Upward
OU2MW-16I (17.5 ft) & OU2MW-16S (5.5 ft)	-0.0024	Downward

Based on calculated vertical head potentials, groundwater impacts near or at monitoring well cluster OU2MW-16 will move upward to the point of discharge with the exception of impacts in the upper 17.5 feet, which will move laterally toward the discharge point. At OU2MW-15, which is over 200 feet further away from Lawrence Creek than OU2MW-16, impacts observed in the upper 32.5 feet will move laterally with little vertical movement. This well cluster is located between the reported subsurface spill location and the impacts observed in the SCDHS monitoring well MGP-11.

Based on the distribution of BTEX and PAH concentrations observed in groundwater and the vertical head potentials calculated at the monitoring well cluster locations, a separate source may be contributing in part to the groundwater impacts observed at MGP-11.

5. Conclusions

The results of the study confirmed that the oxygen injection IRM operating in OU-2 is not deflecting the groundwater plume, does not substantively affect the groundwater elevations, and does not affect the soil vapor concentrations. To date, the IRM has been successful in reducing groundwater concentrations at and downgradient of the injection lines.

Groundwater elevations do not increase substantially during injection, and the minor increases observed (<0.03 feet) are transient and do not propagate far from the point of injection. These increases dissipate immediately after the injection ceases. Further, groundwater concentrations indicate that the edge of the groundwater plume as defined by the 100 ug/L total BTEX or total PAHs limit is accurately depicted and the plume is adequately characterized. As such, the treatment system as designed is sufficient to treat the entire width and depth of the plume at both locations.

A separate source may be contributing to the increased contaminant concentrations observed in the SCDHS well MGP-11, but the exact level of contribution remains unclear. Fortunately, the Manatuck Lane injection line was installed with the capacity to expand the system to cover this area. Therefore, regardless of the source of these impacts, the existing Manatuck Lane injection line was extended southward along Garner Lane in April 2008 to treat this area while further sampling and analysis is conducted to determine the ultimate source.

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