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Bioremediation of a Petroleum and Solvent Plume during Redevelopment of a Municipal Facility

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ABSTRACT: The City of Rochester, New York, completed a major redevelopment project that included building demolition, site remediation, and building of a new Operations Center for the Bureau of Water, Lighting, and Parking Meters. The site was contaminated by petroleum products and chlorinated volatile organic compounds (CVOCs) from the former operations with a groundwater plume of approximately 30,000 square feet. The site presented a number of challenges to remediation including shallow bedrock; a plume of chlorinated ethenes within a plume of benzene; toluene; ethylbenzene and xylenes (BTEX); and the need to complete site remediation beneath occupied buildings without vapor intrusion into offices or work spaces. Based on reducing conditions in the CVOC plume and the high ratio of DCE and vinyl chloride to TCE, injection of electron donor (HRC-X®) to the top of bedrock was completed to stimulate reductive dechlorination. Aerobic bioremediation with oxygen injection was selected for the larger BTEX plume with injection points also installed in the CVOC plume for aerobic treatment following anaerobic dechlorination. CVOCs were reduced to non-detect in the anaerobic treatment zone with no posttreatment rebound. On average BTEX was reduced by 95% after 1 year of remediation with minimal posttreatment rebound in the former source area. Active remediation is complete and the site is currently in closure phase with engineering controls in place.

INTRODUCTION

The new facility includes buildings for storage and maintenance of vehicles and equipment and offices for staff. Remediation alternatives were evaluated for effectiveness and the ability to be implemented safely during all phases of site redevelopment. Groundwater was measured at an average depth of 7 feet below grade in the overburden and within 1 foot of the top of bedrock in bedrock wells. The depth of the overburden ranges from 11.9 to 14.5 feet. Soil consists of sand with lesser amounts of gravel and silt. Bedrock is Penfield Dolostone described as fine to medium-grained, thin-bedded dolomitic limestone with no visible cross-bedding or other depositional features. The upper 10 feet of bedrock is fractured with an average rock quality designation of 54%. Typical of this geologic setting, soil contaminant levels were highest at the overburden/bedrock interface. Fortunately, the extent of the CVOC plume was limited and did not extend deep into more competent bedrock.

After building demolition, approximately 18,000 cubic yards of petroleum impacted soil and weathered bedrock were removed for off-site disposal. A significant portion of the excavation was advanced to the top of bedrock resulting in the near complete removal of the primary source of groundwater contamination. An extensive soil and groundwater sampling program was completed following soil removal and redevelopment of the site proceeded in conjunction with remediation of the groundwater VOC plume. The footprint of the plume beneath the New Operations Center is shown in Figure 1. Groundwater flows to the northeast towards the adjacent Dewey Avenue.

FIGURE 1. New Operations Center and groundwater VOC plume.

Remedial design included geochemistry and microbial analyses. Dissolved sulfate was measured throughout the site but other electron acceptors (oxygen, nitrate, and ferrous iron) were depleted. Monitoring during demolition was used to identify and characterize hotspots within the plume associated with floor drains, oil-water separators and other subsurface features of concern. As a result, there were high variations in contaminant levels and oxygen demand with soluble COD ranging from 26 to 795 mg/L. Groundwater contaminant levels were measured up to 15.8 mg/L total VOCs, 8.16 mg/L BTEX, and 1.45 mg/L CVOCs. Microbial samples were collected using Bio-Trap® samples from Microbial Insights (Rockford, Tennessee) and analyzed using CENSUS which is bases on a quantitative polymerase chain reaction (qPCR). The anaerobic CVOC degrading *Dehalococcoides* was detected in overburden and bedrock wells at concentrations of 8.43E+00, 7.42E+01, and 2.13E+02 cells/bead. Based on reducing conditions in the CVOC plume and the high ratio of DCE and vinyl chloride to TCE, injection of HRC-X® electron donor to the top of bedrock was completed to stimulate reductive dechlorination. HRC-X® is provided by Regensis (San Clemente, California) and consists of a glycerol polylactate compound that is specifically designed to release lactic acid when hydrated. The lactic acid is metabolized by anaerobic microorganisms resulting in the production of hydrogen which is used as an electron donor.

Aerobic bioremediation with oxygen injection (Matrix Environmental Technologies Inc., U.S. Patent No. 5,874,001) was selected for the larger BTEX plume with injection points also installed in the CVOC plume for aerobic treatment following anaerobic dechlorination. Fifty-seven oxygen injection points, including 10 as a biobarrier along Dewey Avenue to prevent off site plume migration, and 2 oxygen injection systems were installed. The oxygen injection points were installed 1 to 2 feet into bedrock with sand pack extending into the overburden. This design provided targeted treatment of the overburden/bedrock interface. A sub-slab depressurization system with a chemical resistant vapor barrier was also installed underneath the new buildings to mitigate potential vapor intrusion. The layout of the aerobic and anaerobic remediation zones are shown in Figure 2.

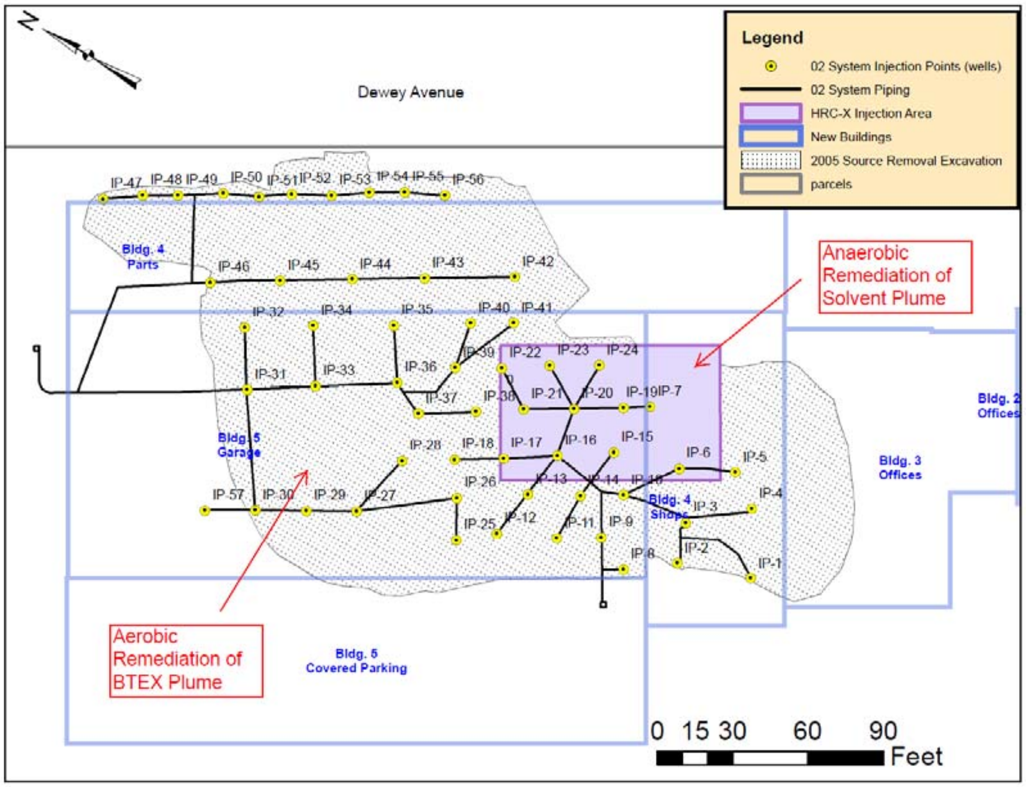

FIGURE 2. Groundwater VOC plume with location of oxygen injection points for aerobic bioremediation and HRC-X® injection area for anaerobic bioremediation.

MATERIALS AND METHODS

Anaerobic bioremediation was initiated following source removal and seven months before the start of aerobic bioremediation. The anaerobic remediation zone identified on Figure 2 is approximately 4,750 square feet. Borings on approximately 10 foot centers were advanced to the top of bedrock using a Geoprobe® direct push machine and 2.25-inch O.D. probe rods. 13 pounds of HRC-X® and HRC Primer® were injected under pressure into each boring. HRC Primer was added for immediate release of lactic acid. The dosing rate was approximately 4.2 pounds per foot and the total product injected was 690 pounds. The dosing rate was conservative and based on 11 mg/L of chlorinated ethenes in groundwater and a safety factor of 3.

Oxygen injection points were generally spaced on 15 to 20 foot centers in the plume and adjusted for accessibility in the new buildings and not to conflict with structural features and utilities. A row of closely spaced injection points, on 10 foot centers, was installed on the down gradient property line adjacent to Dewey Avenue as a biobarrier to prevent off site contaminant migration. The injection points were installed using rotary drilling techniques and advanced one to two feet into weathered bedrock. The injection points were constructed of one-inch I.D. Schedule 40 PVC and included a one foot solid sump at the bottom followed by a one foot section of 0.01 inch slotted screen and riser pipe to the ground surface. Sand filter pack was installed from the bottom of the point to approximately one foot above the top of screen followed by a bentonite seal to above the water table. This design provided the dispersion of oxygen gas into the weathered top of bedrock and the highly contaminated bedrock/overburden interface.

An oxygen supply line was installed to each injection point. The lines consisted of 0.5-inch I.D. high density polyethylene (HDPE) pipe. The lines were installed below grade in shallow trenches and connected to the injection points below grade. 24 injection points in the southern portion of the plume were connected to an oxygen injection system and 33 injection points on the northern portion of the plume were connected to a second oxygen injection system. The logistics of the underground piping runs within the footprint of the new buildings resulted in two separate systems on opposite ends of the New Operations Center.

As shown in Figure 3, high purity oxygen gas was produced on site from ambient air using a pressure-swing adsorption oxygen generator, rotary screw air compressor and refrigerated air dryer. 90% purity oxygen gas was pulse injected from a storage tank using timer controlled solenoid valves and variable area flow meters. The oxygen flow rate, frequency of injection and duration of injection were adjusted on site to optimize the oxygen transfer efficiency to groundwater without producing hazardous vapors.

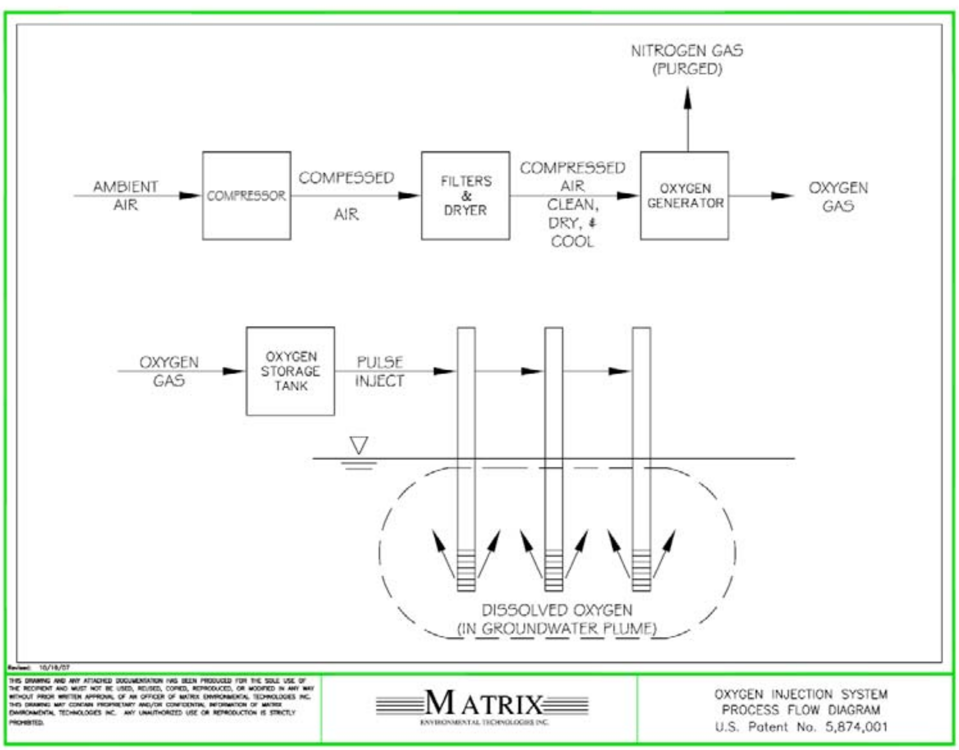

FIGURE 3. Matrix Oxygen Injection System process flow diagram.

Oxygen injection was initiated in the northern half of the plume approximately seven months after the injection of HRC-X®. Oxygen injection was not started in the southern half of the plume until anaerobic dechlorination was nearly complete based on the depletion of TCE and low levels of DCE and vinyl chloride. This was approximately 15 months after the injection of HRC-X®. In both aerobic treatment areas, oxygen was pulse injected 6 times per day at a daily mass injection rate of 2.25 pounds per injection point.

RESULTS AND DISCUSSION

The average dissolved oxygen concentration in groundwater measured from injection points between pulse injections is shown in Figure 4. The objective of oxygen injection included increasing dissolved oxygen to saturation levels in the injection points and maintaining a minimum concentration of 5 mg/L in the plume. Dissolved oxygen averaged 2.9 mg/L in the plume prior to remediation. During oxygen injection, the dissolved oxygen average ranged from 24 to 41 mg/L. Oxidation reduction potential (ORP) increased from a pre-remediation average of -202 mV to a post-remediation average of +10 mV. During anaerobic treatment, ORP decreased to -348 mV in the center of the anaerobic remediation zone and lactic acid was detected in groundwater.

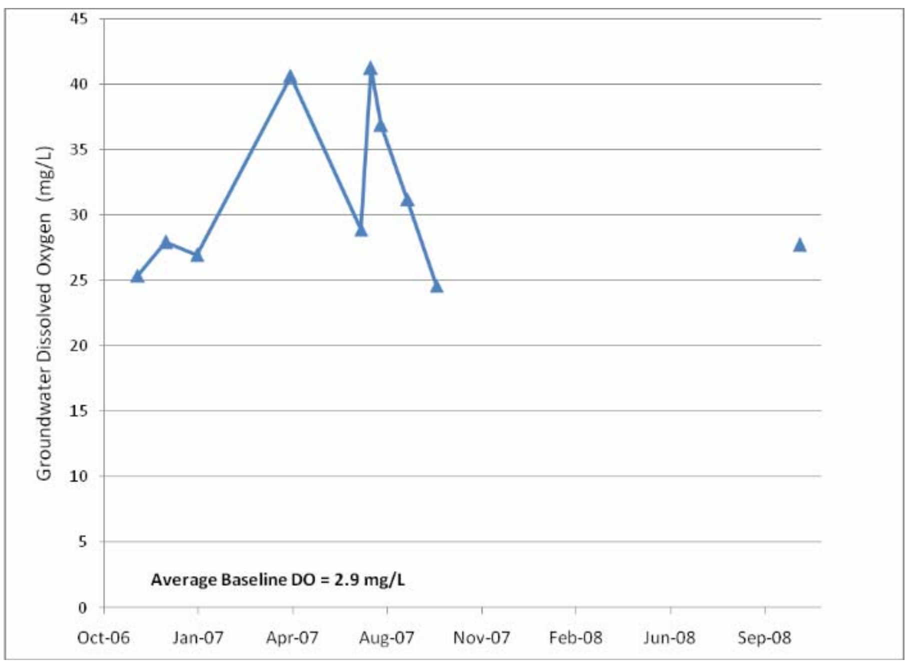

FIGURE 4. Average groundwater dissolved oxygen concentration measured between pulse injections from oxygen injection points.

Groundwater contaminant data are shown in Figure 5 for BTEX and Figure 6 for Total VOCs. The laboratory analytical method was EPA 8260B. Oxygen injection was initiated in October 2006 and ended in June 2009. Groundwater samples were collected from 11 wells including 2 in the barrier, 4 in the anaerobic remediation zone, and 5 throughout the aerobic remediation zone. At the completion of active remediation, 7 of the 11 well samples were non-detect for BTEX. The wells were sampled approximately 6 and 12 months after oxygen injection was ended. 4 well samples remained non-detect, 3 had low levels of BTEX (3.95 to 11.4 µg/L) and 2 showed declining trends in BTEX and total VOCs. Only 2 wells showed post remediation rebound with the final samples measuring 197 µg/L and 999 µg/L for total VOCs. The total VOC reduction from base-line was 94% at both locations and the highest concentration was from a source area (shown as green diamond in Figures 5 and 6). With engineering controls in place, the post remediation concentrations for BTEX and total VOCs are acceptable for closure.

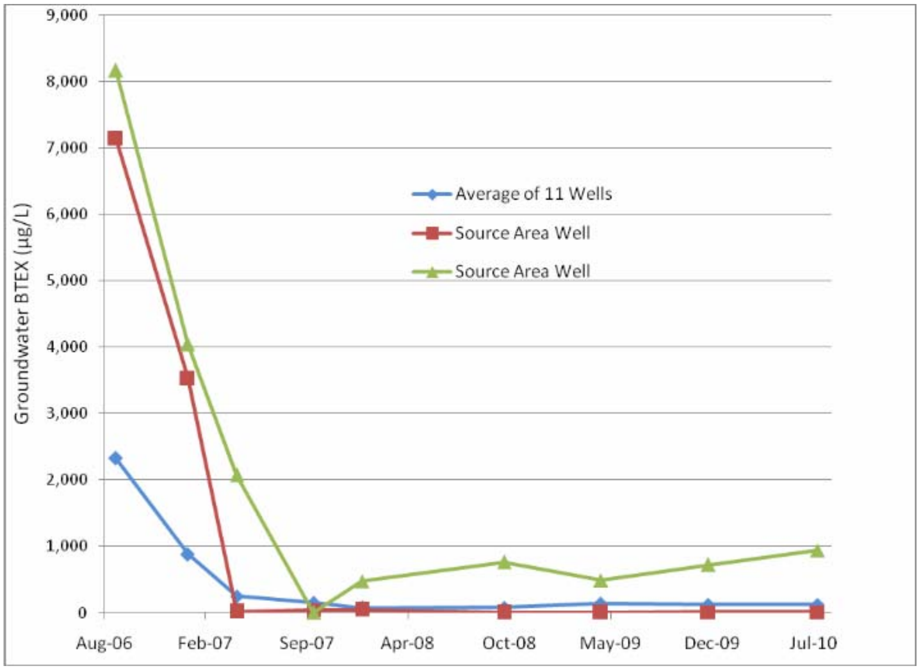

FIGURE 5. Reduction in groundwater BTEX from aerobic bioremediation.

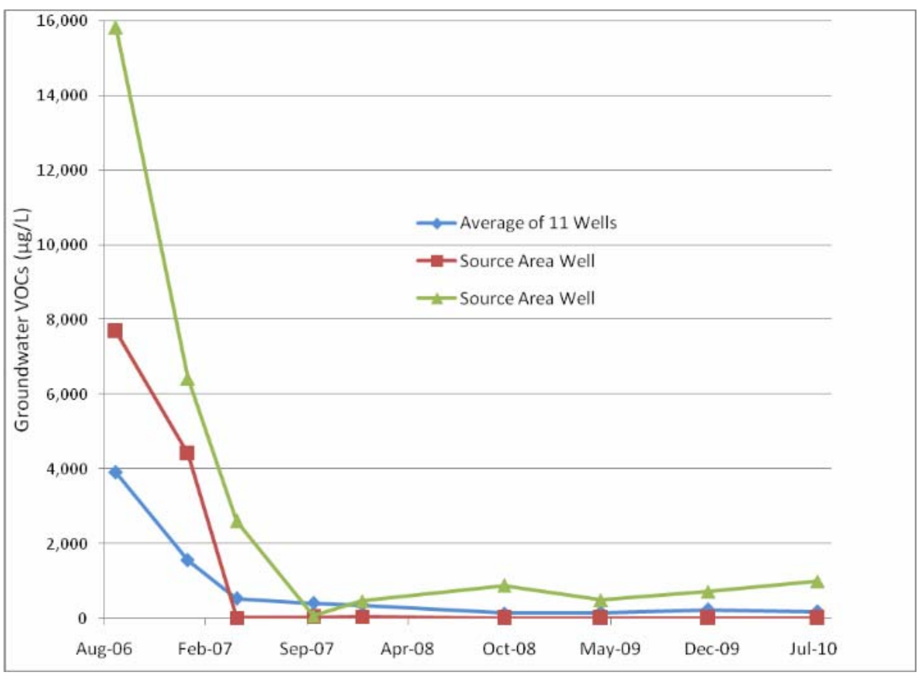

FIGURE 6. Reduction in groundwater total VOCs from aerobic bioremediation.

Groundwater data for CVOCs are shown in Figure 7. Detected CVOCs included TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and vinyl chloride. Samples were collected from 4 wells in the anaerobic remediation zone and 1 well in the aerobic remediation zone located approximately 30 feet from the anaerobic zone. The wells were not in place until after the injection of HRC-X® in March 2006. However, a pre-remediation sample was collected from a well in the anaerobic remediation zone in January 2006 and the concentration was 2,190 µg/L. This well was destroyed during site construction. Approximately 18 months after HRC-X® injection, CVOCs were reduced to non-detect in 3 of the 4 anaerobic zone samples and reduced by 54% in a sample 30 feet outside the zone. One year after the completion of aerobic bioremediation, 4 samples were non-detect and one sample was below the drinking water standard at 3.22 µg/L.

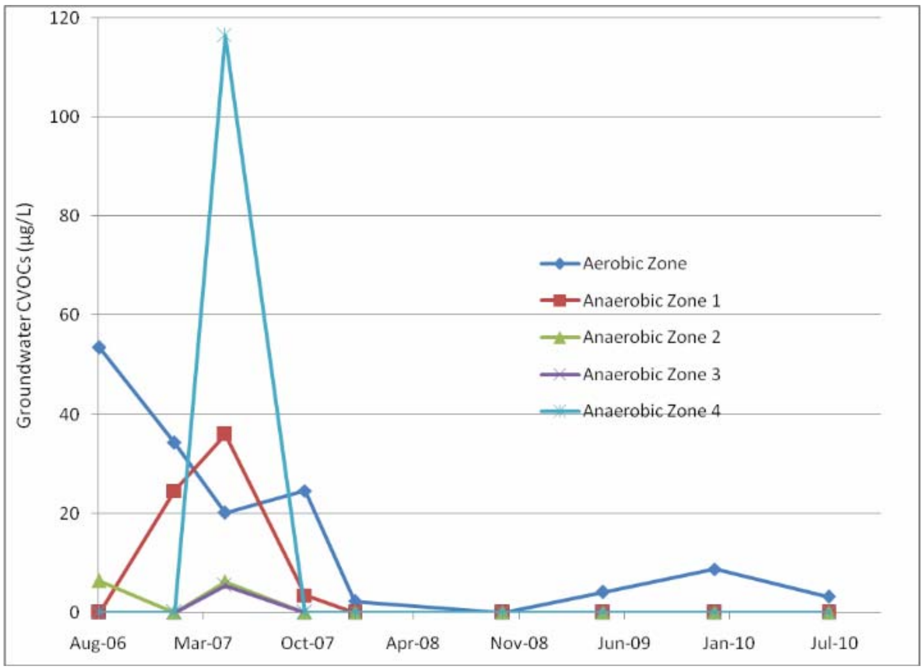

FIGURE 7. Reduction in groundwater CVOCs from sequential anaerobic and aerobic bioremediation.

CONCLUSIONS

Remediation was successfully completed during redevelopment of a municipal facility without delaying building construction or impacting the use of the site for a New Operations Center. The site presented a number of challenges to remediation including shallow bedrock, a plume of chlorinated ethenes within a BTEX plume, and the need to complete site remediation beneath occupied buildings without vapor intrusion into offices or work spaces. Remediation alternatives were evaluated for effectiveness and the ability to be implemented safely during all phases of site redevelopment.

The selected remedy included the removal of approximately 18,000 cubic yards of petroleum impacted soil and weathered bedrock following building demolition. Underground sources of contamination, including underground storage tanks, floor drains, dry wells and an oil water separator were removed. Following source removal, geochemistry and microbial data were collected from overburden and bedrock wells and a groundwater remediation plan was implemented that included anaerobic bioremediation of a chlorinated ethene plume followed by aerobic bioremediation of a larger BTEX plume using oxygen injection.

In the anaerobic remediation zone, CVOCs were reduced from 2,190 µg/L to non-detect with no posttreatment rebound. Oxygen injection was initiated seven months after the injection of electron donor for anaerobic bioremediation. On average BTEX was reduced by 95% after 1 year of oxygen injection, with minimal posttreatment rebound in the former source area. Active remediation is complete and the site is currently in closure phase with engineering controls in place including a sub-slab depressurization system and vapor barrier beneath occupied offices. Extensive source removal, assessment of chemical and biological conditions prior to groundwater remediation and the targeted in situ treatment of the overburden/bedrock interface were key elements to a successful project.

ACKNOWLEDGMENTS

Site remediation was funded in full by the City of Rochester and managed by the Division of Environmental Quality. Regulatory oversight was by the New York State Department of Environmental Conservation, Region 8 Division of Environmental Remediation. The City of Rochester was the recipient of the 2006 New York Chapter Environmental Project of the Year Award by the American Public Works Association. The project also received Gold Certification by the Leadership in Energy and Environmental Design (LEED).

REFERENCES

LaBella Associates, P.C. 2006. *Groundwater Remediation System Design Work Plan*, Operations Center for the Bureau of Water, Lighting, and Parking Meter Operations, 10 Felix Street, Rochester, New York.

LaBella Associates, P.C. 2007. *Nomination for: 2006 Public Works Project of the Year, Environmental Category, City of Rochester Water & Lighting Bureau and DEQ*, American Public Works Association, New York Chapter.

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ROCHESTER 2010
THE RENAISSANCE
City of Rochester, New York
William A. Johnson Jr., Mayor

LABELLA
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MATRIX

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City of Rochester, NY
Bureau of Water, Lighting and Parking Meters

- Constructed between 1913 and late 1930s
- Designated a Brownfield due to soil and groundwater contamination
- City of Rochester was responsible party and developer

New Operations Center

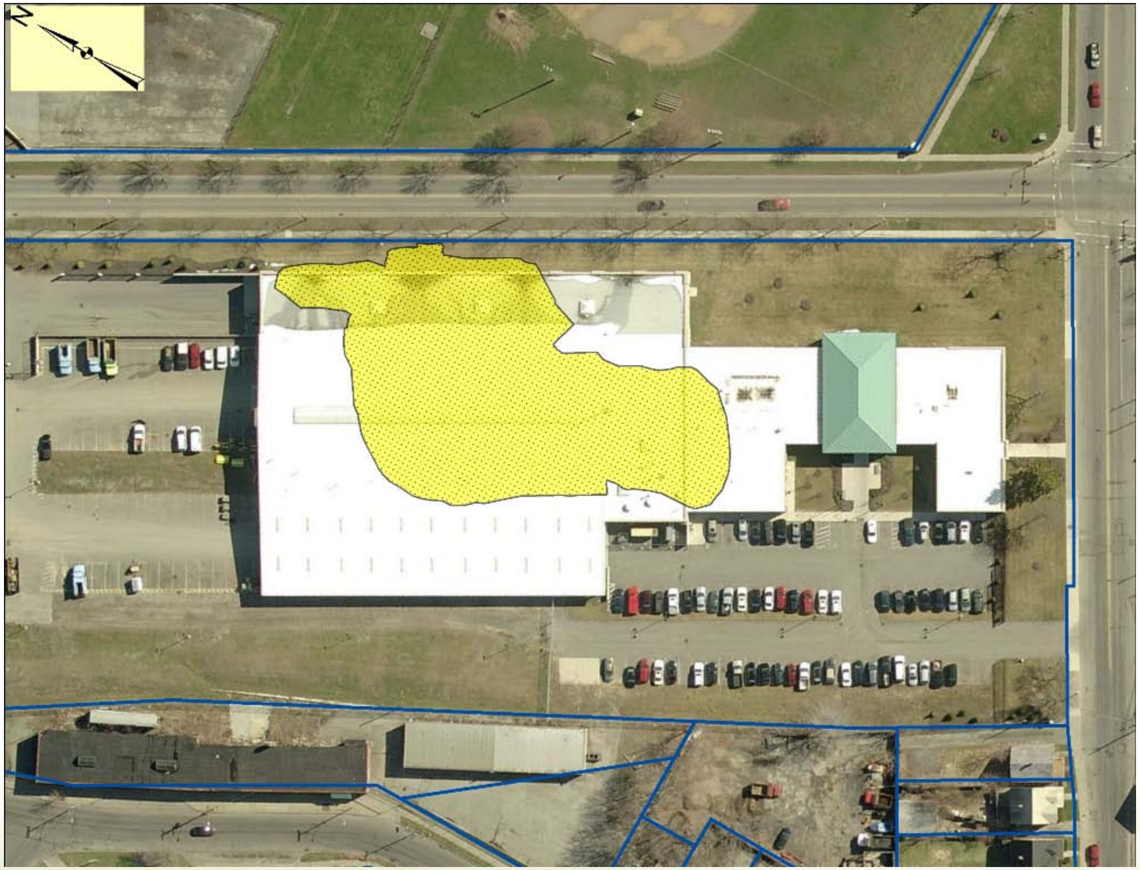
- Demolition, remediation and redevelopment completed in 18 months
- “Green” building design and LEED Certification
- Managed by City of Rochester Dept. of Environmental Services

Geologic Conditions

- Shallow bedrock at 12-15 feet below grade
- Fine to medium grained, thin bedded dolomitic limestone
- Upper 10 feet fractured with average RQD of 54%
- Groundwater at average depth of 7 feet below grade
- Contamination in overburden and upper portion of bedrock
- Contaminant levels highest at overburden/bedrock interface
- Exposure and vapor intrusion concerns in new buildings
- 18,000 cubic yards of impacted soil excavated to top of bedrock
- Primary source of groundwater contamination removed

Soil Excavation to Top of Bedrock

30,000 ft^2 VOC Plume Beneath New Operations Center



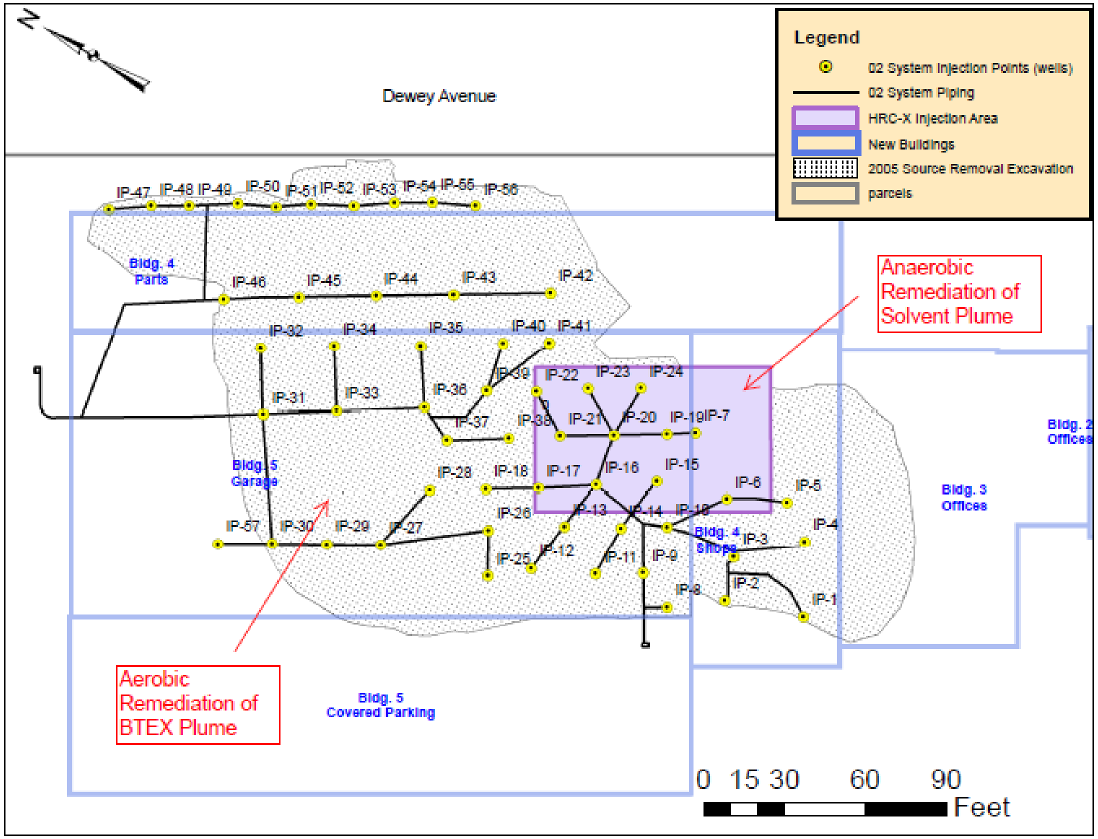
Groundwater Conditions

- Chlorinated VOC plume within a larger petroleum VOC plume
- 15.8 mg/L Total VOCs
  - 8.16 mg/L BTEX
  - 1.45 mg/L CVOCs
- Soluble COD from 26 to 795 mg/L (multiple sources)
- Active anaerobic dechlorination of CVOC plume
  - Average ORP of -202 mV
  - High ratio of DCE & VC to TCE
  - *Dehalococcoides* at 8.43E+00, 7.42E+01 and 2.13E+02 cells/bead
- Active biodegradation of petroleum VOC plume
  - Aerobes and facultative anaerobes
  - Average DO of 2.9 mg/L; precipitation is on going oxygen supply

Remediation Design

- Reductive dechlorination with injection of electron donor
  - 13 lbs of HRC-X® and HRC Primer® injected on 10 ft centers
  - Dosing rate of 4.2 lbs per foot; total 690 lbs injected
- Aerobic biostimulation with pulse injected oxygen gas
  - 47 oxygen injection points in plume; 10 as down gradient barrier
  - Injection points installed 1 to 2 feet into bedrock with sand pack extending into the overburden
  - Oxygen pulsed at 2.25 lbs per injection point per day
- Sub slab vapor barrier and depressurization system

Aerobic and Anaerobic Remediation Zones



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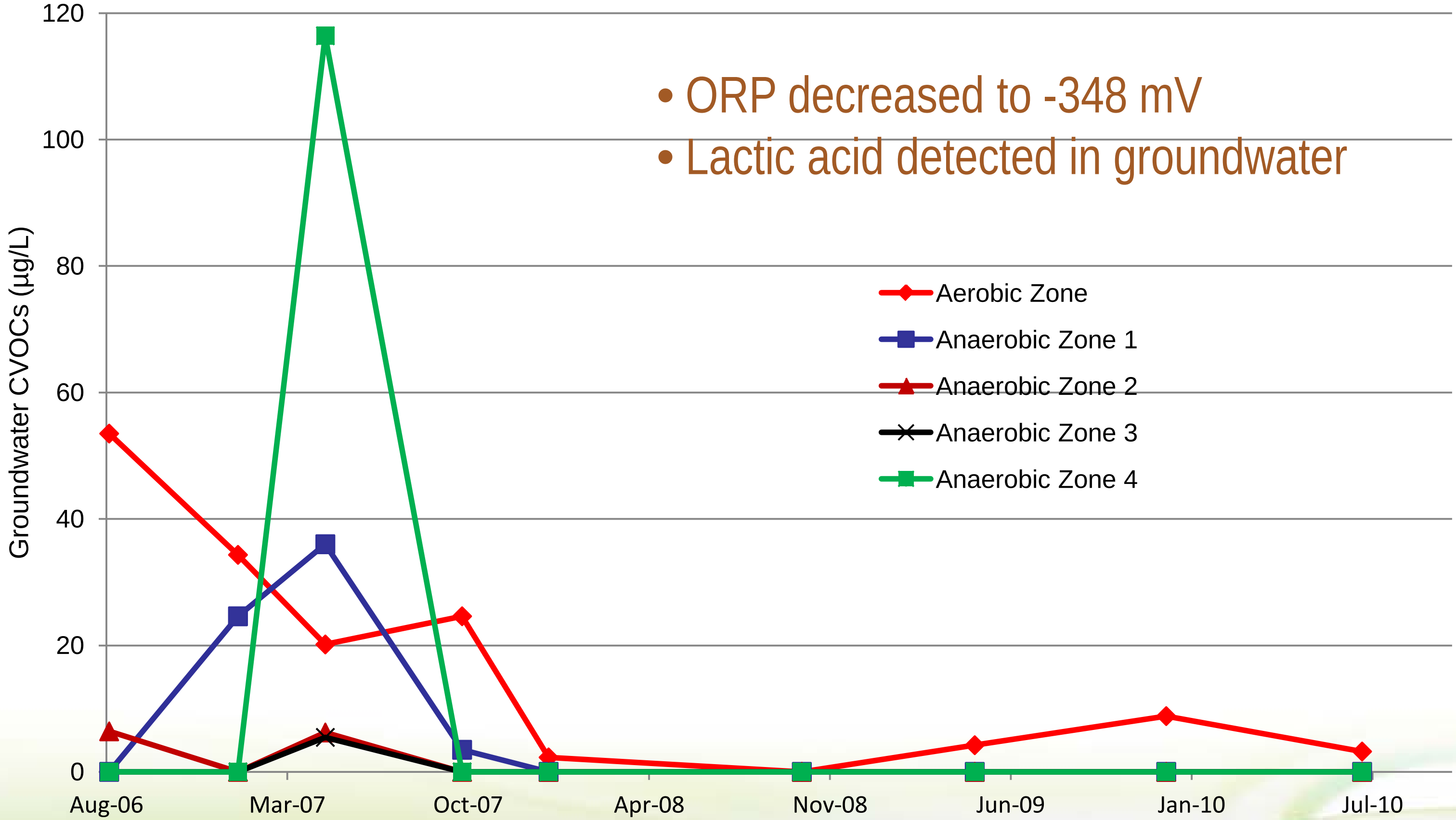
Injection of Electron Donor

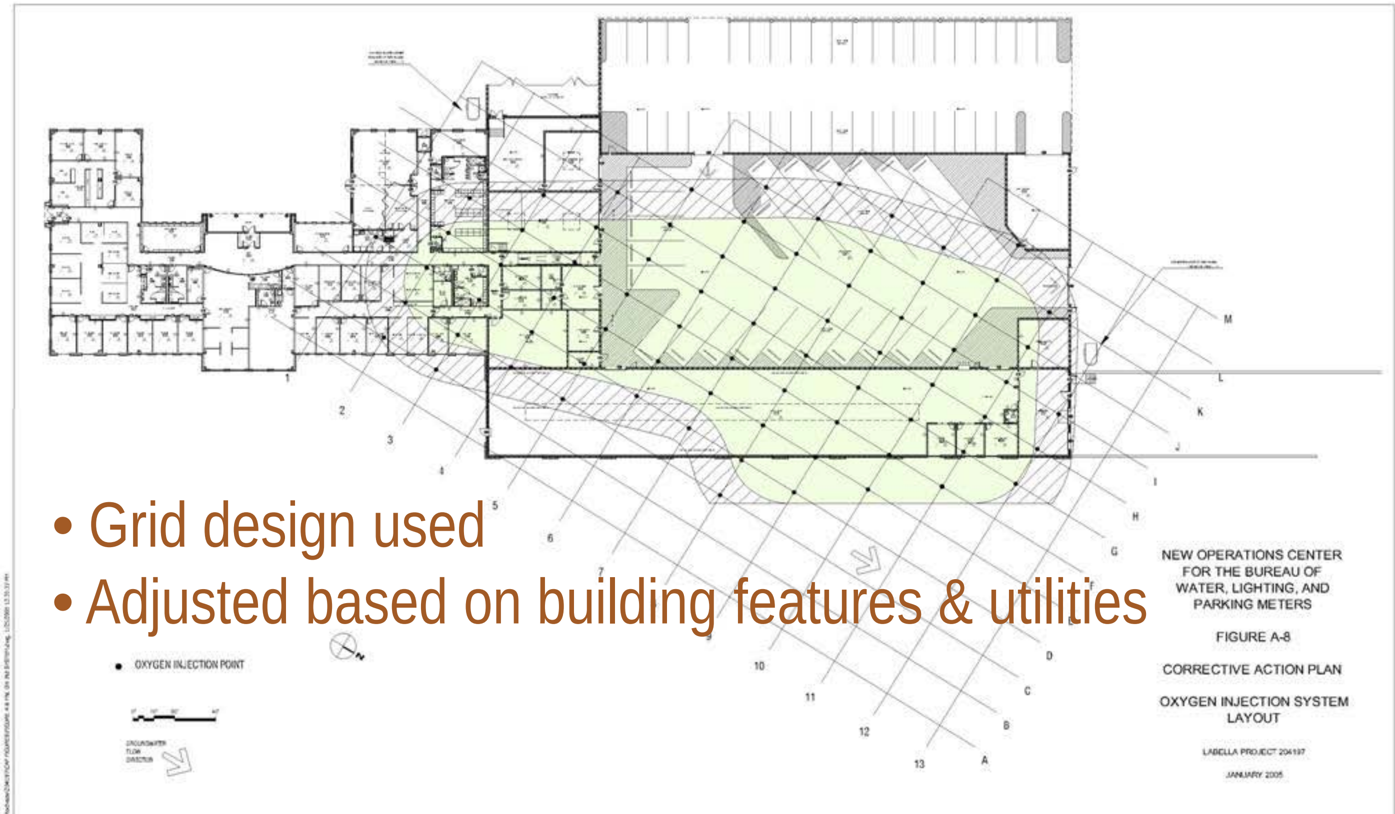
Injection of Electron Donor

Reduction in Groundwater CVOCs



- ORP decreased to -348 mV
- Lactic acid detected in groundwater

Initial Grid Layout of Oxygen Injection Points

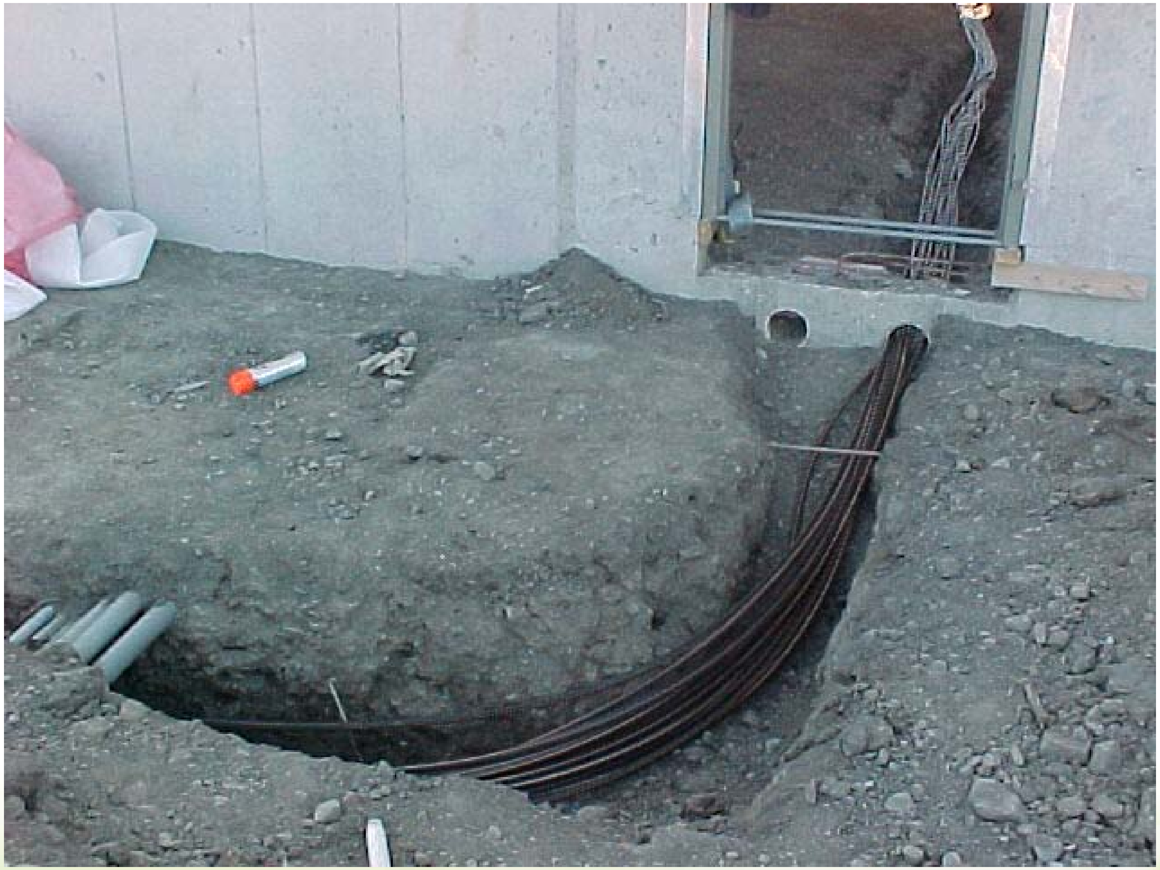


- Grid design used
- Adjusted based on building features & utilities

Oxygen Injection Points and HDPE Piping

Installation in New Building

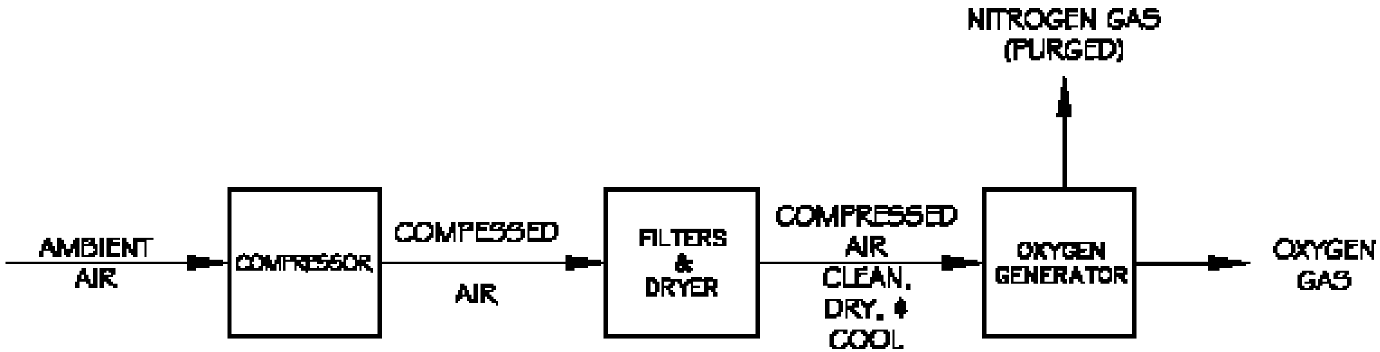
HDPE Piping Runs to Oxygen Injection System



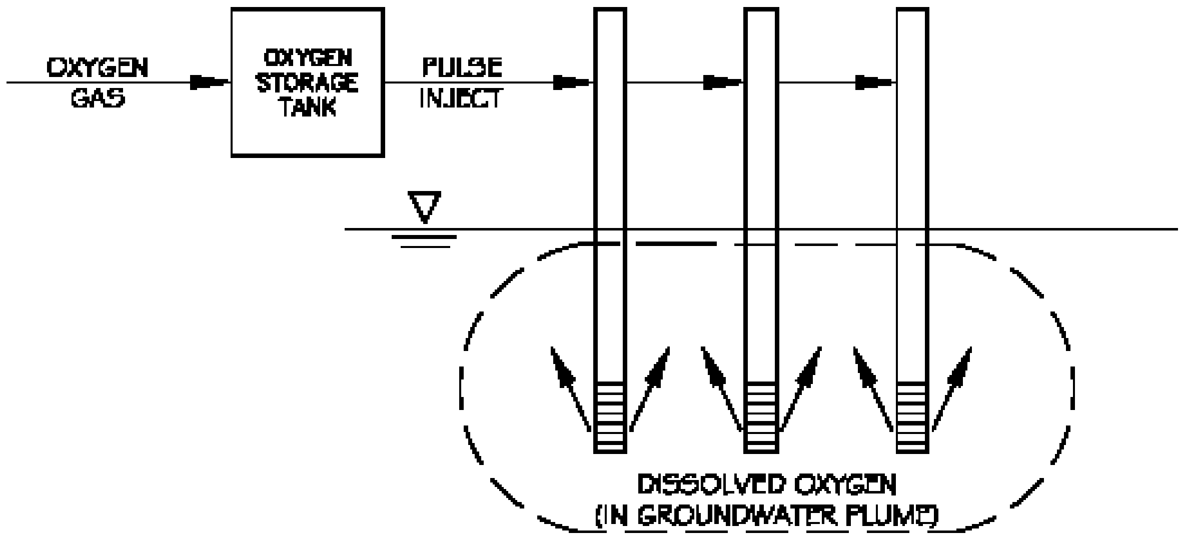
Sub Slab Vapor Barrier

Matrix Oxygen Injection Process (U.S. Patent 5,874,001)

1. Oxygen gas is produced on-site by separating nitrogen from ambient air



2. Oxygen is pulse injected to saturate groundwater with dissolved oxygen (DO) without causing contaminant volatilization or plume migration

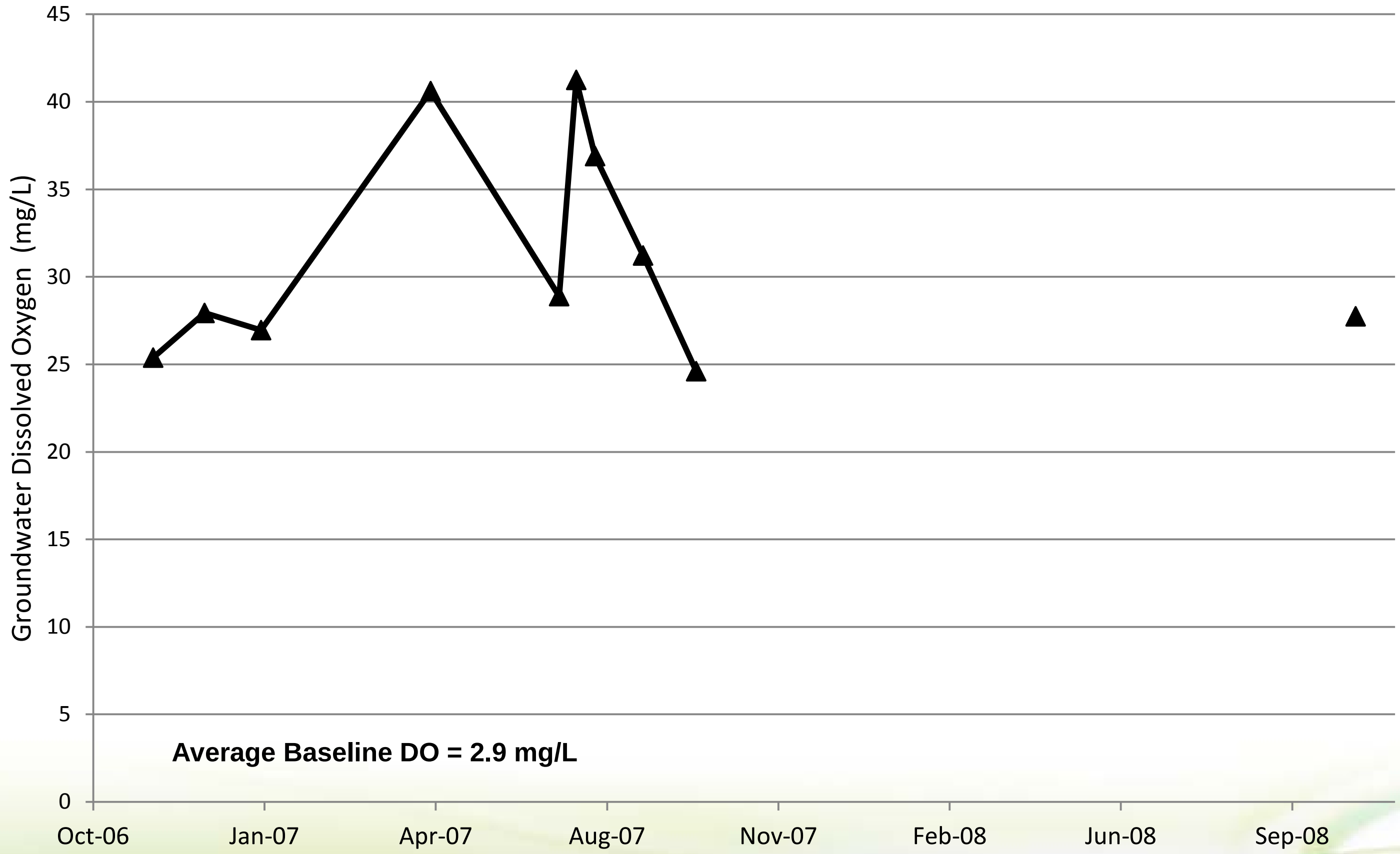


Oxygen Injection System

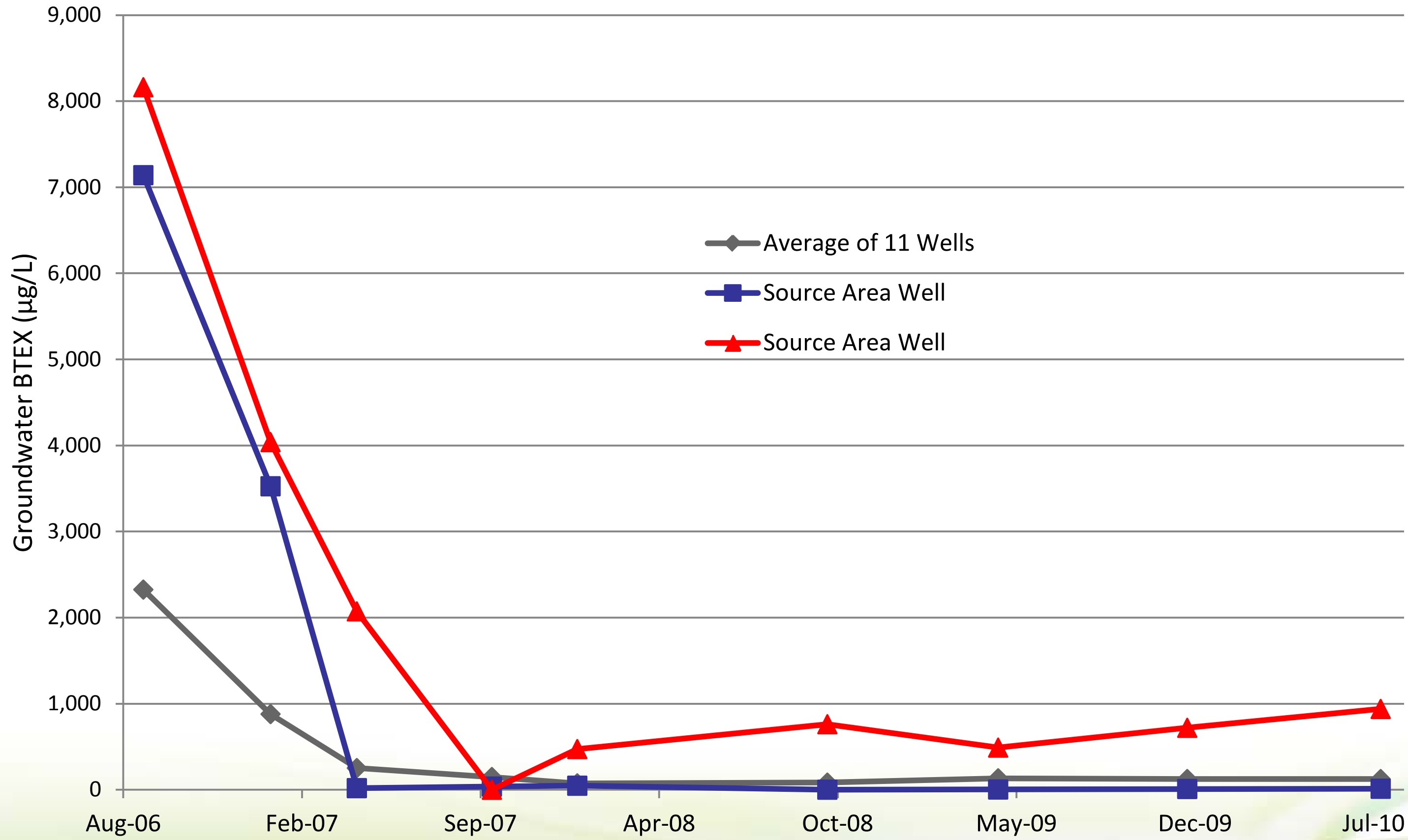
Pressure Swing Adsorption Oxygen Generator

Oxygen Storage Tanks for Pulse Injection

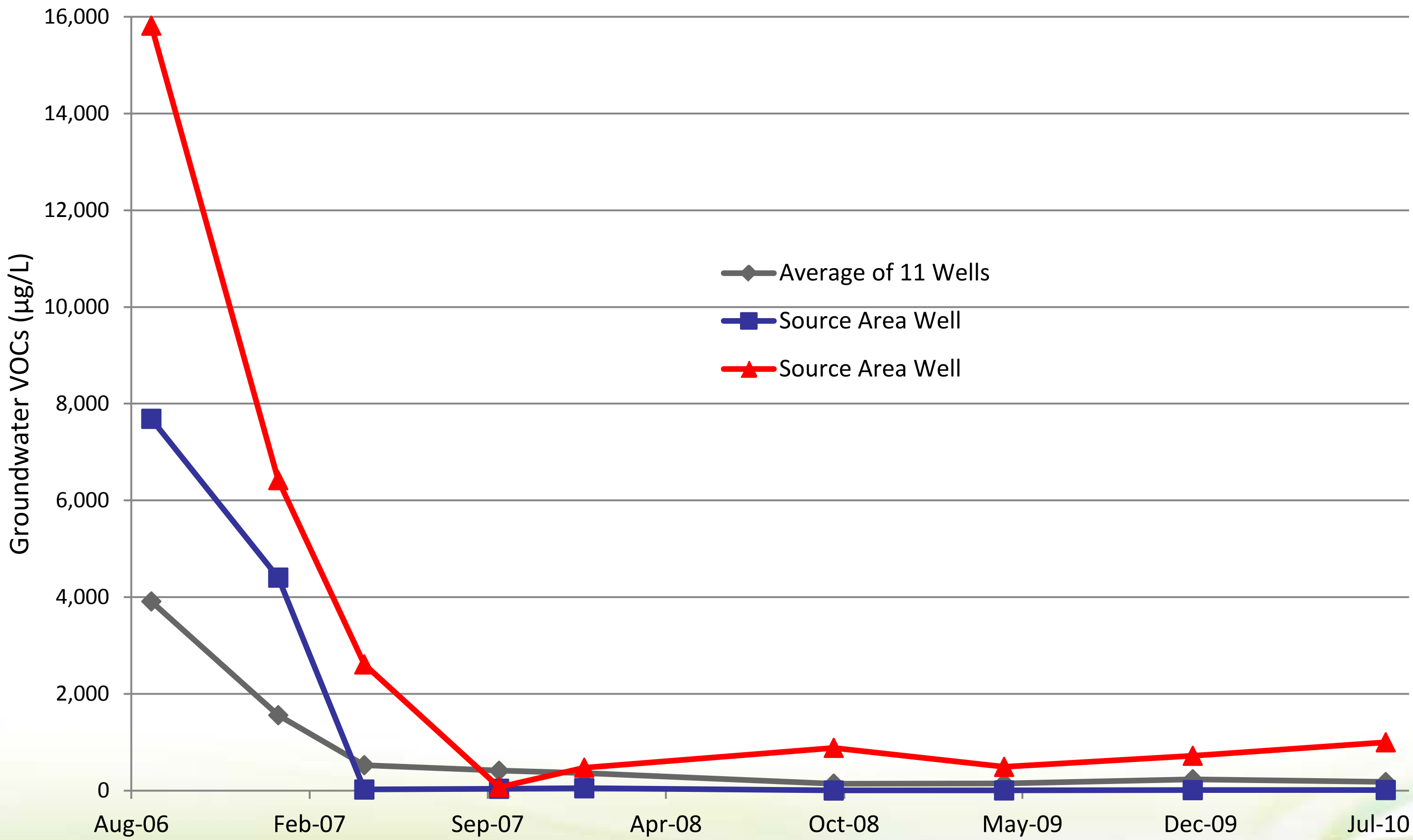
Dissolved Oxygen During Aerobic Remediation



Reduction in Groundwater BTEX



Reduction in Groundwater Total VOCs



Keys to Success

- Remediation was an important part of redevelopment
- Design of remediation infrastructure involved architects and civil engineers
- Extensive source removal (18,000 cubic yards) following building demolition and removal of USTs
- Targeted treatment of overburden/bedrock interface
- Geochemistry and microbial analyses indicated that anaerobic dechlorination followed by aerobic biostimulation was most effective method