Case Study of a VOC Impact to a Potable Resource: The Restoration Pathway

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Abstract

Volatile organic compounds (VOCs) consisting of mainly trichloroethene was identified in groundwater by a series of Remedial Investigation/Feasibility Study (RI/FS) activities, which required remedial action (RA) at a former industrial facility adjacent to a small residential neighborhood. The identified groundwater impact is located within the Triassic Newark Basin, which is a regional aquifer system used as a potable and industrial water source.

The VOC impact at the facility occurs in soil and groundwater in both unconsolidated sediment (shallow) and fractured bedrock (deep). VOC impact in the residential neighborhood occurs in deep groundwater throughout and in shallow groundwater at the far end of the residential neighborhood only. The fate and transport of VOCs in groundwater is complicated by: the differential compaction of glacial till deposits; the interconnection of shallow and deep groundwater zones with a predominant downward flow except at the far down groundwater gradient end of the residential neighborhood where upward groundwater flow occurs; and the north–south orientation of the plume associated with preferential flow through bedrock fractures. RI/FS activities to evaluate impact and RA options has required well installation to a maximum 300 foot depth, domestic to monitoring well conversion, down-hole geophysics, multi-level packer testing, nested piezometer installation, groundwater modeling, etc.

RA based on the RI/FS resulted in the installation/operation of a pump and treat (P&T) system to address deep groundwater impact. The time frame for groundwater restoration with current RA operation is projected for 30 years. Evaluation of RA ability to restore groundwater with research on innovative technologies has been ongoing.

Identification and Initial Response for Evaluating and Addressing an Impacted Potable Resource

The identification of a potable well impact by VOC (or other) constituents of concern for public health typically occur from the following actions:

- Suspected and/or reported release investigation of a commercial or industrial facility;
- Property transfer or bank financing activities requiring environmental conditions audit/investigation;
- Public water supply sampling as part of a regular monitoring program; and
- Private potable well sampling by public health organizations as part of a monitoring initiative and/or objectionable taste and odor reported by private citizens.

For the subject of this case study, indication of a potable groundwater resource impact resulted from a complaint by a resident to the local county department of health (DOH) that their well water had a bad taste and odor (refer to Figure 1 for location). Subsequent sampling conducted by the DOH identified the presence of elevated VOC concentrations consisting of mainly trichloroethene (TCE) at the residential potable wells in the Neighborhood (high TCE concentration of 65,000 µg/L) and at a production well (PW-1) of an industrial facility (Facility) immediately south of the Neighborhood (high TCE concentration of 66,000 µg/L). Other potable supply wells analyzed for VOCs outside of the Neighborhood and the Facility area showed non-detectable to minimal concentrations not considered to be a concern. Based on the DOH data, a temporary water supply was established for Neighborhood residents and the DOH ordered residents to cease using their potable wells to prevent exposure. Later, the Neighborhood residents were permanently connected to a public water supply. The DOH also conducted a test pit study at five locations on the Facility property with soil sampling results indicating TCE concentrations ranging from 5 to 13,000 µg/kg. DOH held hearings to identify potential responsible parties (PRPs) for the groundwater impact source, but no determination was made due to insufficient information.

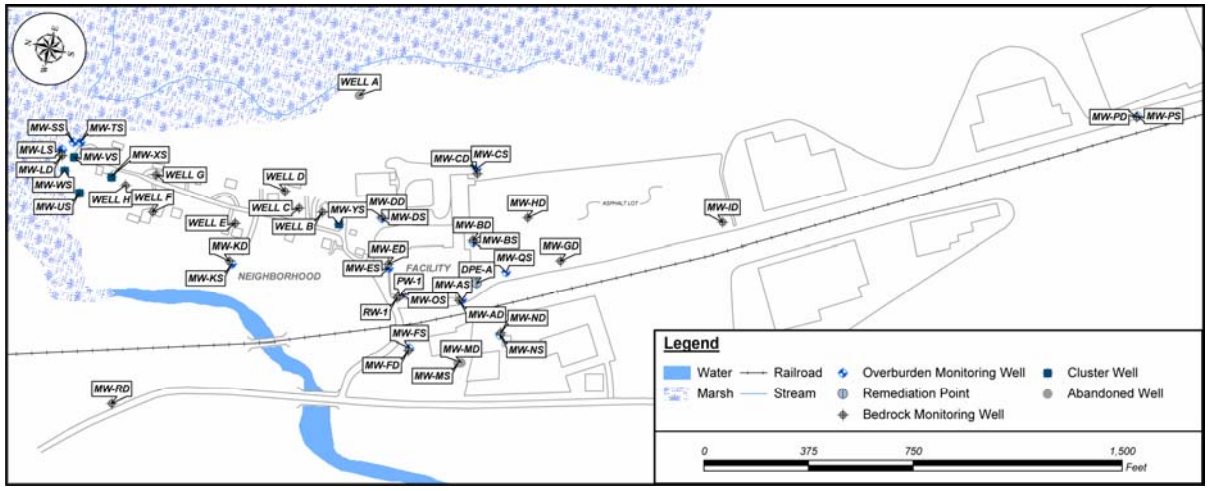

Figure 1: Study Area Base Map

Initial Investigation Summary

Stemming from the DOH documented groundwater impact, the state regulatory agency (State) sponsored Phase I and II investigation activities using an environmental consultant subcontractor to identify PRPs. Later, the parent company of the company who operated the Facility (operations were ceased) south of the Neighborhood sponsored investigation activities under an agreement with the State. Since beginning investigation activities, three environmental consultant companies have been involved with the project towards characterizing the Facility and surrounding area including the Neighborhood (designated the Study Area) and design a remedial system to address the residual VOC impact to the groundwater system and soils.

Initial investigation activities involved shallow soil gas sampling (25 locations), surface geophysical studies (seismic refraction and magnetometer), soil boring/monitoring well installation (six overburden wells MW-AS through MW-FS and nine bedrock wells MW-AD through MW-ID) with soil and groundwater sampling, and groundwater sampling of a former potable well associated with a demolished house in the immediate vicinity of the Facility (refer to Figure 1). The results of the initial investigation activities conducted showed VOCs, mainly TCE, as the constituent of concern impacting the groundwater system. The overburden and bedrock wells all showed TCE concentrations with the highest overburden well concentration detected at MW-BS (1,800 µg/L) and highest bedrock well concentration detected at MW-AD (33,000 µg/L). Soil VOC concentrations in the vadose zone were reported as non-detect to low estimated concentrations. The soil gas investigation did not show VOCs to be a concern. No other constituents analyzed were shown to be a concern.

Remedial Investigation/Feasibility Study Activities Summary

The Facility entered the State supervised Super Fund Program with the signing of a Remedial Investigation/Feasibility Study (RI/FS) Consent Order superseding the previous agreement with the State for the Facility. The initiation of RI/FS activities at the Facility began with the development of an RI/FS Work Plan by a second environmental consulting company selected by the parent company. The overall purpose of the RI/FS Work Plan was to detail continuing evaluation activities of the Facility for potential remaining VOC impact in soil and groundwater (source identification and physical/chemical characterization). Ultimately, the goal was to design and implement remedial actions to address the identified impact.

A series of RI/FS activities were initiated for evaluating the Facility to identify potential sources and preferential pathways for impact(s) to the environment. These activities involved conducting interviews with historic personnel, researching historic documents, historic air photo review, utility survey, potable well search, and physical canvassing of building. Further site characterization activities included: a shallow soil gas investigation (57 sample locations), a test pit investigation (six locations), soil probe investigation (26 locations sampled with groundwater samples collected from select locations/depths), soil boring investigation (five locations) with rock coring and groundwater sampling from temporary wells at select locations, aquifer testing at all accessible well locations, and groundwater sampling of the inactive site production well (PW). Additionally, trenches were excavated to further define potential residual VOC impacted soil areas (from soil gas and soil probe activities) at the southern portion of the Facility building in preparation for remedial excavation as an interim measure to remove VOC impacted soil acting as a continuing groundwater system contamination source.

To develop a conceptual model of the entire Study Area and improve understanding of the transport mechanisms through the subsurface environment, additional delineation of the VOC impact was necessary. With assistance from the State, property access to the

residential properties was for continuing RI/FS activities by the Environmental Alliance, Inc. (Alliance) for the project.

The RI/FS activities conducted involved: removal of pumps from the Neighborhood potable wells; installation of overburden wells MW-KS through MW-TS and bedrock wells MW-KD through MW-PD and MW-RD to expand definition of groundwater quality across the Study Area (refer to Figure 1); establishment of a groundwater monitoring program incorporating existing monitoring wells, Facility production well PW-1, and selected Neighborhood wells - well A, well B, well C, well D, well E, well F, well G, and well H (refer to Figure 1); down-hole geophysical study (down-hole video, natural gamma, spontaneous potential, single-point resistance, temperature, fluid resistivity, caliper, heat-pulse, and brine tracing) and packer testing of select bedrock wells across the Study Area; aquifer (slug) testing of wells within the Neighborhood; pump and treat (P&T) pilot testing of bedrock wells MW-AD and H; and development of a computer groundwater model for the Study Area.

Remedial Investigation/Feasibility Study Results Summary

The site investigation and RIFS activities have provided a comprehensive understanding of the geologic and hydrogeologic conditions as well as the extent of VOC impact in the Study Area, which was used to create a site conceptual model.
The unconsolidated sediments are comprised of Pleistocene and Recent unconsolidated glacial till sediments consisting of clay and silt with unsorted variable grained sand, coarse gravel and boulders with a variable thickness of 15 to 20 feet that has been observed to be reworked by the nearby river and associated alluvial deposits in various locations. The glacial till/alluvial deposits are underlain by lodgment till, which is glacial till compacted by the weight of an overlying glacier as it advances. The lodgment till can resemble bedrock in appearance and density and act as a reduced permeability zone and was observed to have a variable thickness of about 15 to 20 feet. The lodgment till is underlain by sedimentary bedrock at about 40 feet below grade (bg) identified as the Triassic Age Brunswick Formation, which is part of the Newark Group in a regional Triassic Basin. The Brunswick Formation consists of shale inter-bedded with sandstone and siltstone and/or mudstone with high clay content. The bedrock is fractured with the frequency of fractures

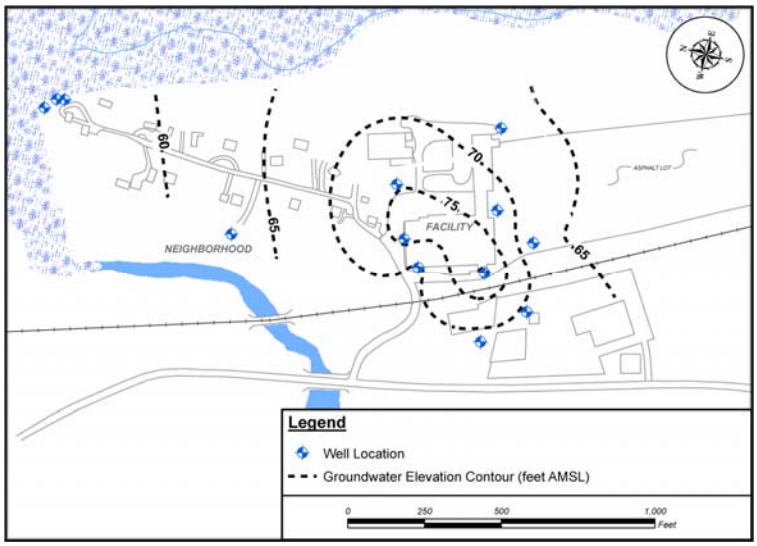

Figure 2: Overburden Well Groundwater Gradient Elevations

decreasing with increased depth. The observed fractures are the major pathway for groundwater movement through the bedrock.

Groundwater flow direction at the overburden and bedrock wells of the Facility is generally northward with the overburden wells showing a more radial flow pattern at the Facility and the bedrock wells showing an open ended trough along the main road that runs through the middle of the Neighborhood (refer to Figures 2 and 3, respectively).

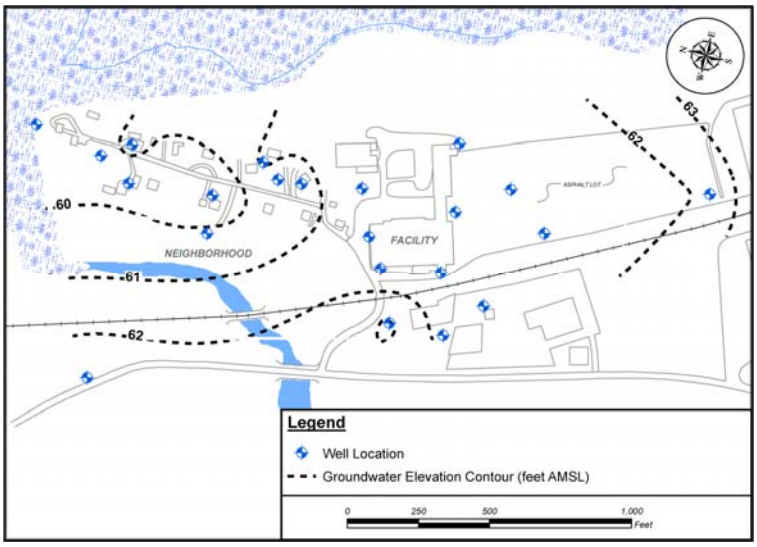

Figure 3: Bedrock Well Potentiometric Surface Elevations

From the groundwater elevation data, a vertical groundwater flow component for the Study Area groundwater system is predominantly downward through unconsolidated sediments and bedrock with two exception areas. The exception areas were observed at the up groundwater gradient wells MW-PS and PD (sentinel wells to confirm non-impacted groundwater) located approximately 2,400 feet south of the Facility building where the bedrock well showed artesian conditions and down groundwater gradient wells MW-LS and LD located approximately 1,250 feet north of the Facility building where an upward vertical gradient from bedrock to unconsolidated sediments was observed. The upwelling of groundwater from bedrock to unconsolidated sediments at the MW-LS and LD wells at the end of the Neighborhood along with downward movement of groundwater across the remaining well locations (except MW-PS and PD) highlights the hydraulic interconnection of the different lithologies and allows for the identification of Study Area groundwater as a single system.

The site investigation and RI/FS analytical data confirmed initial DOH data in showing VOCs, mainly TCE, as the main constituent of concern in the Study Area groundwater. The highest TCE concentrations in overburden groundwater (160,000 µg/L - mobile laboratory) and bedrock groundwater (200,000 µg/L – fixed laboratory) were reported from temporary wells installed within soil borings located at the southern portion of the Facility building. Permanent well locations DPE-A (pilot test point) and MW-AD in the southern portion of the Facility analyzed for VOCs by a fixed laboratory showed high TCE concentrations of 79,000 µg/L and 51,000 µg/L, respectively. The overburden wells at the perimeter of the Facility show non-detect to moderate TCE concentration (< 500 µg/L) range to the north, east, south, and west. The bedrock wells at the perimeter of the Facility show non-detect to moderate TCE concentration (< 500 µg/L) range to the east, south, and west. Groundwater analytical data in the Neighborhood showed elevated TCE concentrations at the

bedrock wells in the tens of thousands of µg/L from the north end of the Facility to the down groundwater gradient end of the Neighborhood (MW-LD) with concentrations as high as 38,000 µg/L (well A). Overburden wells from the Facility extending into the Neighborhood showed TCE as non-detectable or low estimated concentrations. The exception is MW-LS having shown a range of concentrations from non-detect to 26,000 µg/L. The elevated concentrations observed at MW-LS are associated with impacted groundwater from the bedrock upwelling into the unconsolidated sediments at the north end of the neighborhood. Refer to Figures 4 and 5 for representative TCE concentrations at overburden and bedrock wells, respectively. TCE in soil and soil gas was identified by the site investigation and/or SRFI activities only at the southern portion of the Facility building with a high TCE soil gas concentration of 30.2 ppm (via mobile laboratory) and high TCE soil concentration of 42,000 mg/kg (via fixed laboratory).

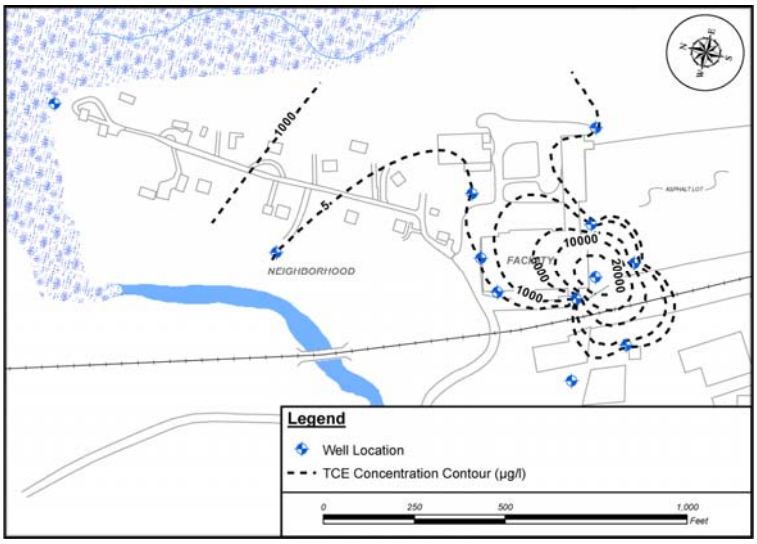

Figure 4: Overburden Well Groundwater TCE Isoconcentration Contours

Based on the physical and chemical characterization data for the Study Area, TCE groundwater impact appears to stem from the southern portion of the Facility migrating vertically downward through the unconsolidated sediments (pore space, cracks, partings, etc.) and bedrock (fractures) with lateral movement along the groundwater flow paths into and through the Neighborhood where at the far north end an upward groundwater flow allows a portion of the impacted groundwater to rise into the unconsolidated sediments.

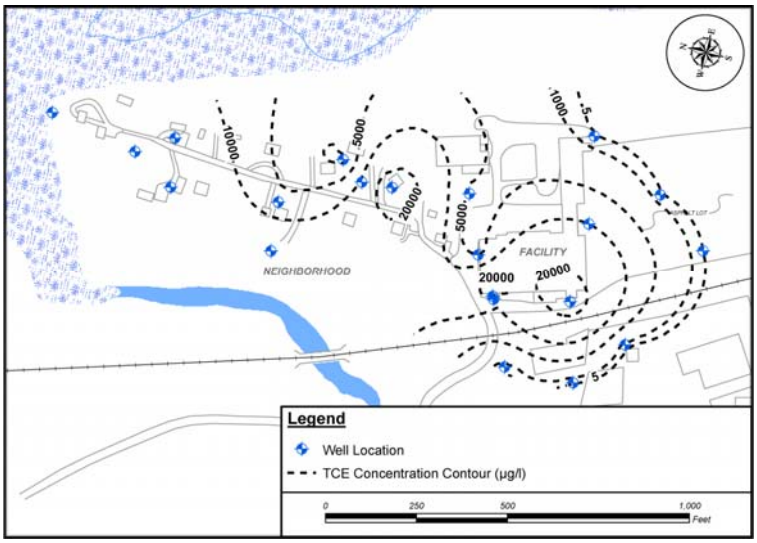

Figure 5: Bedrock Well Groundwater TCE Isoconcentration Contours

The groundwater computer model was created and calibrated using the Study Area geologic and hydrologic data, including the P&T pilot test data,

to simulate Study Area conditions as accurately as possible for the prediction of contaminant particle transport. Once calibrated, the model was tasked to run various pumping conditions from specific well point construction and locations to predict contaminant transport through bedrock (and unconsolidated sediment). This was used to evaluate if P&T operating conditions and recovery well location/construction will address the VOC groundwater plume. The model demonstrated that a recovery well at the northwest corner of the Facility operated at a sustainable flow rate of 115 gallons per minute and constructed to a minimum depth of 250 feet would be capable of creating a groundwater capture zone to cover the entire Facility area and extend to well F and well G in the Neighborhood. Additionally, this P&T system configuration had the potential of influencing bedrock groundwater past well H and the upwelling of groundwater from bedrock to unconsolidated sediments at MW-LS and LD. Based on this data, the P&T system was considered a reasonable remedial action option to address VOCs in groundwater.

The Draft RI/FS Report documented the characterization data and remedial action evaluation (includes details of pilot studies and computer modeling) with recommendation for the P&T technology to address the Study Area wide VOC impact to bedrock groundwater. After addressing State and public comment issues regarding the Draft RI/FS Report with proposed remedial actions, the State approved the P&T remedial technologies for the Study Area VOC impacts in a Record of Decision (ROD).

Remedial System Design and Construction

Design activities for the P&T remediation systems involved property owner negotiations, permitting (Federal, State, and local), process design, contractor and equipment procurement, operation and maintenance schedule, monitoring schedule, and remedial goals. As part of the design report, contingency remediation technology enhancements including *in-situ* chemical oxidation (ISCO) technologies and i*n-situ* Bioremediation via Anaerobic Reductive Dechlorination (ARD) technologies were included should remedial goals not be achieved. The activities for remediation system design were conducted concurrently with the development of a remedial program Consent Order.

The P&T remediation system design as constructed consists of recovery well RW-1 (formerly MW-OD installed to a depth of 300 feet bg) with a 4-inch Grundfos submersible pump capable of a 150 gpm flow rate. The pump with hard piping was set at 230 feet bg. A pressure transducer to monitor water level for pump operation was set at 225 feet bg. RW-1 is connected through subsurface piping to a treatment building housing a groundwater treatment train consisting of a sediment filter, two air strippers connected in series, and two carbon units connected in series with discharge to a stream under State equivalency permit.

Remediation System Operation, Monitoring, and Evaluation

P&T remediation system operation was initiated at a pumping rate of 30 gpm. Attempts to increase the pumping rate during start-up and shake-down of the P&T system

resulted in the drawdown of groundwater to the low level alarm set at 210 feet bg, which shut-down the pump. A voltage frequency regulator was installed to operate the pump system at variable pump rates to accommodate the flow rate below pump specifications. The P&T system is currently operated at a pump rate of 15 gpm to maintain a maximum continuous pump rate that the groundwater system can support. Since initiation, the P&T system has treated 26,827,640 gallons through April 2006.

All wells in the Study Area (except artesian well MW-PD up groundwater gradient of the Facility) have shown a drawdown response with initiation of P&T remediation system operation with wells installed into bedrock exhibiting greater drawdown than wells installed in the overburden. Continued P&T system operation has shown well hydraulic heads to fluctuate in response to groundwater system recharge and operation of pumping well RW-1 although influence over the groundwater system has been maintained. This occurrence is an indication that the P&T system is capable of influencing the defined extent of impacted groundwater and highlights the hydraulic connection of groundwater between bedrock and overburden. The noted upwelling at MW-LS and LD area has continued since the initiation of the P&T system although reduced (lesser difference in groundwater elevation) and for some time periods has reversed (groundwater elevation at MW-LS was greater than the MW-LD groundwater elevation).

TCE concentrations in groundwater at the established point of compliance (POC) bedrock wells MW-AD, MW-DD, MW-KD, and MW-LD for the Study Area historically showed initial decreases at all locations after P&T initiation followed by variable concentration increases and decreases in response to the influence of pumping conditions on the groundwater system and groundwater system recharge. A comparison of POC wells TCE data from pre-remediation to April 2006 is presented below.

POC Well	Pre-Remediation TCE Data*	April 2006 TCE Data*	TCE Percent Reduction
MW-AD	26,000	120	99.5
MW-DD	5,700	2,800	50.8
MW-KD	5,500	ND	100
MW-LD	9,500	1,000	89.5
* - Concentrations in µg/L ND - Not Detected			

Table 1: Bedrock Well TCE Concentration Comparison

The TCE data in Table 1 indicates reductions at the POC wells since P&T system operations were initiated although the historically MW-KD and MW-LD data during P&T system operation has been in the thousands of µg/L. The cause for such fluctuations can be associated with P&T system influence on the groundwater system and the natural condition effecting TCE groundwater concentrations.

A comparison of Neighborhood overburden wells MW-KS, MW-LS, MW-SS, and MW-TS TCE data from pre-remediation to April 2006 is presented below.

Well	Pre-Remediation TCE Data*	April 2006 TCE Data*	TCE Percent Reduction
MW-KS	ND	ND	NA
MW-LS	3,000	770	74.3
MW-SS	6,800	1,500	78
MW-TS	6,700	530	92
* - Concentrations in µg/L ND – Non-Detect			

Table 2: Overburden Well TCE Concentration Comparison

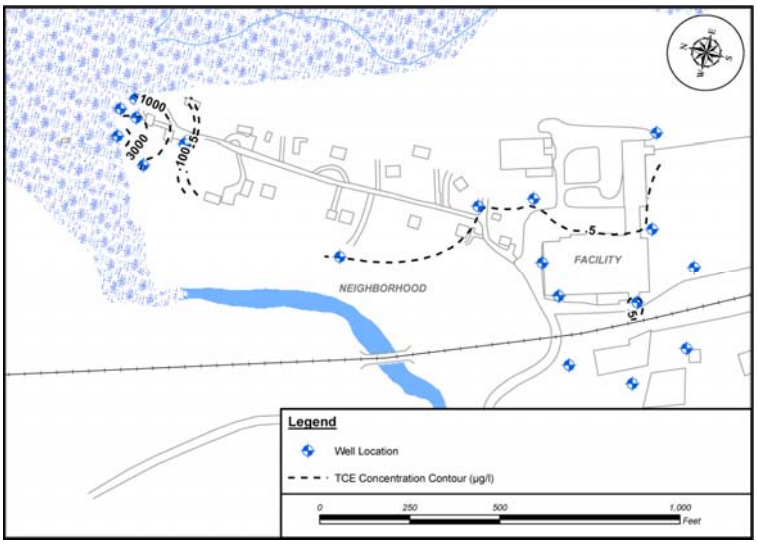

Figure 6: Overburden Well Groundwater TCE Isoconcentration Contours

Figures 6 and 7 for recent bedrock and overburden well TCE concentrations, respectively.

The P&T system is addressing TCE concentrations in groundwater at the majority of Study Area with bedrock wells at the northern portion of the Neighborhood influenced to a lesser extent than wells closer to RW-1. The P&T system is

Table 2 indicates TCE reductions at the Neighborhood overburden wells. Based on the TCE data, the presence of TCE in unconsolidated sediments at the north end of the Neighborhood associated with upwelling of groundwater from bedrock still persist with TCE concentrations decreasing southward away from well MW-LS to non-detect at MW-KS. Cluster wells MW-US through MW-XS installed in the vicinity of wells MW- LS and KS to better delineate TCE impact in the glacial till, lodgment till, and top of bedrock (S,I,D wells, respectively) has shown TCE concentrations consistent with the Neighborhood overburden wells with TCE concentrations reduced to hundreds of µg/L at SW-XS (S,I). Additionally, cluster well MW-YS (S,I) shows the non-detectable TCE concentrations at the south end of the Neighborhood, which indicates impact from the Facility property is not moving into the Neighborhood. Refer to

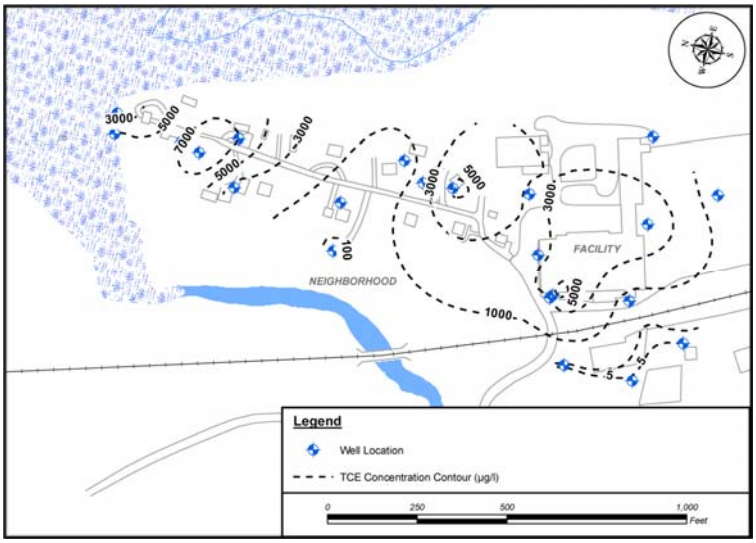

Figure 7: Bedrock Well Groundwater TCE Isoconcentration Contours

also showing influence on TCE concentrations in overburden wells at the north end of the Neighborhood. The installed P&T system is performing close to projected design. However, elevated residual TCE and other associated constituent concentrations in groundwater persist and the impacted groundwater at the north end of the Neighborhood mayl not be adequately addressed in a timely fashion solely by continuing operation of the existing P&T system. To better address the residual TCE concentrations in groundwater at the north end of the Neighborhood, as well the entire Study Area, enhancement of the existing P&T remediation system is being further researched.

Remediation System Enhancements

Based on the Study Area conditions observed and a review of the most applicable remedial technologies, the following remedial technologies are considered for combined use to expedite remediation of TCE in the Study Area groundwater system with continued operation of the existing remediation system:

- Active recirculation and passive injection technologies;
- *In-situ* chemical oxidation technologies; and
- *In-situ* anaerobic bioremediation ARD process technologies.

The active recirculation and passive injection technologies in conjunction with *in-situ* chemical oxidation and anaerobic bioremediation technologies are envisioned to be applied as part of a treatment train (implementation of a series of treatment technologies towards achievement of remedial goals) with ARD as the final technology used. The use of these remedial technologies can address residual TCE concentration in the northern portion of the Study Area while enhancing the long term effectiveness of the existing P&T system to address TCE across the Study Area.

The overall conceptual design for treatment of the residual TCE in the northern portion of the Study Area if necessary consists of a three phase approach. The first phase would be to establish localized hydraulic control of the aquifer system by converting existing well H to a remediation pumping well. The new remediation well would enhance the hydraulic control in this area while providing water for injection of chemical oxidation and *in-situ* bioremediation ARD process applications via the installed injection wells and injection gallery. The second phase would be to utilize RegenOx ^{tm} to chemically oxidize the accessible TCE in the groundwater system at the northern end of the Neighborhood only. The third phase would be to create an anaerobic environment in the groundwater system at the north end of the Neighborhood. Initially for the third phase, substrates such as methanol, vegetable oil, or other appropriate material would be injected to stimulate the naturally occurring microbes to create anaerobic conditions. After some period of conditioning the groundwater system to create the anaerobic conditions, microbes cultured from the Study Area and, if necessary, specialized engineered microbes could be added to further the degradation process for TCE. If determined to be necessary, this approach will relatively quickly reduce TCE concentration in the groundwater system to minimize potential

volatilization issues and create a long term anaerobic environment capable of further reducing TCE concentrations.

Based on the conceptual design the establishment of the *in-situ* bioremediation ARD process may also aid in treating remaining portion of the plume in the reduction of TCE as the current P&T system may be able to draw a newly established ARD treatment zone back to RW-1. Additional injection wells (newly installed or existing) and application of chemical oxidizers, substrates, and/or microbes to address the remaining portions of the TCE plume would be considered as appropriate. The implementation of these remediation system enhancements would be pending regulatory approval and procurement of an Underground Injection Permit.