FOURTH FIVE-YEAR REVIEW REPORT FOR
TIBBETTS ROAD SUPERFUND SITE
STRAFFORD COUNTY, NEW HAMPSHIRE

Prepared by

U.S. Environmental Protection Agency
Region 1
BOSTON, MASSACHUSETTS

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8/20/18
Date

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LIST OF ABBREVIATIONS & ACRONYMS

ARAR	Applicable or Relevant and Appropriate Requirement.
BTEX	The gasoline components Benzene, Toluene, Ethylbenzene and Xylene.
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act.
CFR	Code of Federal Regulations.
DGR	Directed Groundwater Recirculation.
EPA	United States Environmental Protection Agency.
FYR	Five-Year Review.
ICs	Institutional Controls.
ICL	Interim Cleanup Level.
MNA	Monitored Natural Attenuation.
NCP	National Oil and Hazardous Substances Pollution Contingency Plan.
NHDES	New Hampshire Department of Environmental Services.
NPL	National Priorities List.
OU	Operable Unit.
O&M	Operation and Maintenance.
PCB	Polychlorinated biphenyl.
PCE	Perchloroethylene.
PFBS	Perfluorobutanesulfonic acid.
PFOA	Perfluorooctanic acid.
PFOS	Perfluorooctanesulfonic acid.
PRP	Potentially Responsible Party.
RAO	Remedial Action Objectives.
RIFS	Remedial Investigation and Feasibility Study.
ROD	Record of Decision.
SLVWD	Swain's Lake Village Water District.
SVOC	Semi-Volatile Organic Compound.
TBC	To be considered.
TCE	Trichloroethylene.
UE	Unrestricted Exposure.
UU	Unlimited Use.
VER	Vacuum-enhanced groundwater recovery.
VOC	Volatile Organic Compound.
1,2-DCE	cis-1,2-Dichloroethylene.
µg/L	Microgram per liter or parts per billion.

I. INTRODUCTION

The purpose of a Five-Year Review (FYR) is to evaluate the implementation and performance of a remedy in order to determine if the remedy is and will continue to be protective of human health and the environment. The methods, findings, and conclusions of reviews are documented in FYR reports such as this one. In addition, FYR reports identify issues found during the review, if any, and document recommendations to address them.

The U.S. Environmental Protection Agency (EPA) is preparing this five-year review pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Section 121, consistent with the National Contingency Plan (NCP)(40 CFR Section 300.430(f)(4)(ii)), and considering EPA policy.

This is the fourth FYR for the Tibbetts Road Superfund Site. The triggering action for this policy review is the completion date of the previous FYR. The FYR has been prepared due to the fact that hazardous substances, pollutants, or contaminants remain at the site above levels that allow for unlimited use and unrestricted exposure (UU/UE). The Site consists of a single Operable Unit (OU) for the groundwater remedy that will be addressed in this FYR.

The Tibbetts Road Superfund Site Five-Year Review was led by Darryl Luce, EPA Superfund Project Manager. Participants included Kenneth Richards, New Hampshire Department of Environmental Services (NHDES), Richard Sugatt, EPA Risk Assessor, Sarah White, EPA Community Involvement Coordinator, and Eve Vaudo, EPA Senior Enforcement Counselor. The Potentially Responsible Party (PRP) was notified of the initiation of the FYR. The review began on 10/16/2017.

Site Background

The Tibbetts Road Site (the "Site") is located in a rural, residential area of Barrington, NH. At the time of the release, the Site was the residence of Alexander Johnson and his family. In the 1950s, Mr. Johnson would transport partially-filled drums of waste solvent and other hazardous materials in his personal vehicle from Ford Motor Company (Ford), his place of employment in Somerville, Massachusetts, to his home for storage and use as a fuel and accelerant. This practice continued until the Ford manufacturing line in Somerville closed in 1958. The drums with their contents were stored uncovered, in stacks on his property. As the drums deteriorated, the contents gradually began discharging onto the ground and ultimately migrated to groundwater.

During the 1970s and through to the present, residential development replaced the surrounding wooded areas. Groundwater was the source of drinking water until the early 1980s when contamination was found in nearby residential wells. Many of the new neighbors began noticing the drums in the wooded area surrounding the Johnson residence and reported that to Town and State Officials in 1982.

TIBBETTS ROAD FIVE-YEAR REVIEW SUMMARY FORM

SITE IDENTIFICATION		
Site Name: Tibbetts Road		
EPA ID: NHD989090469		
Region: 1	**State:** NH	**City/County:** Barrington/Strafford

SITE STATUS	
NPL Status: Final	
Multiple OUs? No	**Has the site achieved construction completion?** Yes

REVIEW STATUS
Lead agency: EPA
Author name: Darryl Luce
Author affiliation: U.S. Environmental Protection Agency
Review period: 10/16/2017 - 8/20/2018
Date of site inspection: 4/10/2018
Type of review: Policy
Review number: 4
Triggering action date: 8/28/2013
Due date: 8/20/2018

II. RESPONSE ACTION SUMMARY

Acting on complaints from nearby residents in 1982, State of New Hampshire officials discovered more than 300 drums at Mr. Johnson's residence and evidence of releases to the environment. Subsequent inspections found that the contents of many of the drums had discharged onto the ground or were used to burn cars for scrap. These discharges and uses resulted in the contamination of soil with volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), polychlorinated biphenyls (PCBs), and dioxin. Some of these compounds migrated to groundwater resulting in groundwater contamination with VOCs, acetone, and gasoline components including benzene, toluene, ethylbenzene and xylene (BTEX).

In 1984, EPA removed 337 drums containing solvents, PCBs, and other hazardous materials from the property. Subsequent to that, EPA and the State excavated and removed over 405 cubic yards of soil contaminated by solvents and PCBs from the Site, incinerated 3.5 cubic yards of soil contaminated with dioxin, and identified contaminated groundwater in nearby residential drinking water wells. The Site was finalized for inclusion on the National Priorities List (NPL) on June 10, 1986.

In 1987 EPA and the State built a drinking water treatment plant and water distribution network to serve approximately 45 homes whose wells were contaminated or threatened by groundwater contamination from the Site. A group of residents surrounding the Site formed the Swains Lake Village Water District (SLVWD) to assume responsibility for the operation and maintenance of the water supply system and began operating the drinking water plant in 1988.

EPA released the results of a Remedial Investigation and Feasibility Study (RIFS) for public comment on June 24, 1992 and following the comment period signed a Record of Decision (ROD) on September 29, 1992 selecting a remedy for the Site. In 1995, EPA, the State, and the SWLVD negotiated a Consent Decree with Ford, the Potentially Responsible Party (PRP), in which the PRP agreed to improve and fund the drinking water supply system operated by the SLVWD and to conduct the remedial action at the Site.

The RIFS found that the only remaining contaminated media were overburden and bedrock groundwater. The Remedial Action Objective in the ROD was to restore the overburden and bedrock aquifer groundwater. Groundwater was found to be contaminated with VOCs and metals that included arsenic and manganese. The ROD remedy was to extract contaminated groundwater, treat that water to remove the contamination and return that water to the aquifer.

To perform the remedy, the PRP demolished the original Johnson residence that had been damaged by fire and more than ten-years of abandonment; cleared, graded, and paved the approximately 2-acres that overlay contaminated groundwater. The PRP began operation of the vacuum-enhanced groundwater recovery (VER) system in 1996. The VER system removed both contaminated groundwater from the overburden aquifer and contaminant vapors, treated the water and vapors by carbon filtration and the water, once clean, was recharged into the aquifer.

In 1998, EPA determined that although the VER system had not reached cleanup levels in the overburden aquifer, it had reached the limit of its effectiveness and allowed the PRP to shutdown the VER system. The VER system had removed more than 800 pounds of contaminants from the overburden aquifer. The PRP removed the asphalt cap but retained the system on-site, using it to address hotspots that were uncovered by periodic geoprobing and to pulse the system as contaminants slowly desorbed from the aquifer matrix. EPA issued an Amended ROD on September 28, 1998 (the "1998 AROD"), changing the groundwater remedy to bioremediation and phytoremediation with "hot-spot" remediation using the existing VER system.

Approximately 1,600 hybrid poplar trees were planted at the Site in May of 1998 as part of the phytoremediation component of the 1998 AROD. The Preliminary Close-Out Report was signed by the EPA on September 29, 1998, signifying the completion of the construction activities at the Site.

The selected remedy for contaminated bedrock groundwater in the 1998 AROD was Monitored Natural Attenuation (MNA). Calculations performed for the 1998 AROD demonstrated that overburden groundwater would reach cleanup concentrations in 2012. Contaminant concentrations in the bedrock groundwater north of the Site remained high and it was assumed that once overburden concentrations reached cleanup levels that the bedrock concentrations would also decline to cleanup levels. In 2003, the PRP began a series of pilot studies to determine the efficacy of *in situ* remedies in the bedrock groundwater, examining the effects of permanganate injections among others, to potentially hasten the remediation.

In 2008, construction of new homes in the Cedar Creek subdivision began just outside of the limit of a Groundwater Management Zone designed to prevent the use of groundwater, southeast of the Site. In December 2011, a short time after the first residents moved in, four bedrock drinking water wells in the new subdivision were discovered to be contaminated with low concentrations of Site contaminants. To address this, the PRP installed in-home treatment systems to provide clean drinking water to those affected and continued to monitor groundwater. The PRP then began planning improvements to the SLVWD as well as extending service to those homes. EPA and the State began working with the Town of Barrington, NH and its Planning Board to enact an Ordinance to extend and strengthen the zone over which groundwater use is prevented.

In anticipation of adding the new homes to the SLVWD, the PRP began making improvements to the water treatment plant in 2012 to improve the water quality distributed to residents and to meet the demands of more users. The original source for the water treatment plant was the surface water of Swain's Lake. Swain's Lake is a shallow impoundment used primarily as a recreational lake for the residents that border it. This created many problems with the need to sanitize and treat the water. The PRP and the SLVWD replaced that source in 2012 with two wells on 75+ wooded acres donated for that purpose. These wells have been demonstrated to be hydraulically isolated from Site groundwater.[1]

During this time, EPA worked with the Town of Barrington to put in place an ordinance to restrict the use of groundwater in a wider area and require new subdivisions and homes to be responsible for future improvements to the SLVWD. A final Ordinance was passed by the Barrington Planning Board on March 11, 2014.[2] The PRP began construction of the waterline to serve the Cedar Creek subdivision in Spring 2014 and completed it by that Fall.

In 2015, one well in the southeast corner of the Site, 10S, had high concentrations of VOCs. After a drilling program to determine the extent of impacts, the PRP excavated the area surrounding that well, removed 408 tons of aquifer materials, sent those materials off-site for treatment, filled the excavation with clean soil, and replaced well 10S with well MW-308. Since the excavation, well MW-308 has remained below ICLs.

Additional details regarding the Site and the performance of the remedy are discussed in Appendix B.

III. PROGRESS SINCE THE LAST REVIEW

The 2013 FYR made an overall protectiveness statement regarding groundwater, the only OU at the Site. It found the remedy at the Tibbetts Road Site to be *Protective in the Short-Term*. The 2013 FYR finding:

> The remedial actions taken are protective of human health and the environment in the short-term because there are no completed exposure pathways. However, to be protective in the long-term, a number of follow-up actions are necessary: extend the current drinking water system to an existing residential subdivision impacted by bedrock groundwater contaminants, install additional bedrock monitoring wells and perform hydrologic analysis as directed by the approved work plan to determine the limit of influence on the Site bedrock groundwater contaminants, expand institutional controls

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[1] Arcadis, Summary of Environmental Monitoring, 2016, p. 10, September 2017.

[2] Town of Barrington, New Hampshire, Zoning Ordinance as Amended, March 11, 2014.

through a municipal ordinance to include areas that may influence the migration of contaminants in bedrock groundwater, evaluate additional measures to reduce bedrock groundwater concentrations and implement those that are successful, and remove soils in an area of overburden groundwater contamination.

The issues identified by the 2013 FYR responsive to the statement above are in Table 1, below, and apply to both Overburden and Bedrock groundwater. Groundwater is "Site-wide" and the only OU.

Table 1: Status of Recommendations from the 2013 FYR
Issue #1: Contaminated bedrock groundwater has migrated to the Cedar Creek subdivision. Continued use of groundwater will induce further migration and potentially contaminate additional drinking water wells. **Recommendation**: Abandon all drinking water wells on Cedar Creek and provide water through an alternative means. **Current Status**: Completed Fall 2015. **Implementation Description**: All wells to the new homes on Cedar Creek were severed and a new waterline was extended to each of 16 existing homes. Two curb stops were left for homes not yet constructed.
Issue #2: High concentrations of contaminants in bedrock fractures may migrate further outside the limits of the Institutional Controls. Determine the limit of potential migration. **Recommendation**: Perform additional monitoring, geochemical and hydrologic work to determine the bedrock aquifer properties. **Current Status**: Completed 2017. **Implementation Description**: Multi-level monitoring was performed in select bedrock wells and a sentry well, 28R, was drilled adjacent to Hall Road, between the Site and the water supply wells, to determine if the new SLVWD wells influenced contaminated groundwater at the Site. No influence was found.
Issue #3: Because of highly transmissive bedrock fractures, new groundwater users outside the current limits of the Institutional Controls may induce migration of bedrock groundwater contamination. **Recommendation**: Expand the area of Institutional Controls to those areas identified that may cause the migration of contaminants or adversely affect the remedial action. **Current Status**: Completed March 2014. **Implementation Description**: The Town of Barrington, NH enacted a zoning ordinance over a larger area to prevent influencing the contaminated groundwater.
Issue #4: Bedrock groundwater high concentrations of contaminants. **Recommendation**: Evaluate additional measures to reduce bedrock groundwater concentrations. Perform and evaluate directed groundwater recirculation using persulfate oxidizing compound as a treatability study. **Current Status**: Began in 2014, continuing. **Implementation Description**: Directed Groundwater Recirculation has been employed in bedrock to determine effectiveness. Although benzene and, to a small degree, metals were addressed, chlorinated VOCs were not affected in a few locations. Additional work is being performed to assess pumping rates and locations.
Issue #5: Overburden groundwater in one well remains contaminated with toluene above ICL. **Recommendation**: Remove contaminated soil in area surrounding well and continue monitoring to assess effectiveness of removal. **Current Status**: Completed Fall 2015. **Implementation Description**: 408 tons of contaminated soil surrounding well 51S were excavated and treated off-site with low-temperature thermal desorption. The grade was restored with clean fill. Monitoring to assess effectiveness has continued.

IV. FIVE-YEAR REVIEW PROCESS

Community Notification, Involvement & Site Interviews

A public notice was made available to the press on 2/20/2018, entitled "EPA Begins Reviews of 24 New England Site Cleanups during Current Fiscal Year" stating that there was a five-year review and inviting the public to submit any comments to the U.S. EPA. The results of the review and the report will be made available at the Site information repository located at Barrington Public Library, 105 Ramsdell Lane, Barrington, NH.

The EPA project manager contacted John Scruton, Barrington Town Manager, and Marcia Gasses, the Barrington Town Planner. Neither had any issues or concerns regarding the Site. On April 10, 2018, the State project manager, Ken Richards, NHDES, and Darryl Luce, EPA project manager, met with Stan Swier, who lives directly across the street from the Site and also is a Commissioner of the SLVWD and its only operator as of this writing, as well as Richard Sullivan and Scott Haynes of Arcadis, representing the PRP. Mr. Swier had no issues with the Site nor with the operations at the SLVWD. Because Mr. Swier is retiring from running the EPA-built drinking water treatment plant after 32 years of service, Ford is funding the contracting of an operator at the SLVWD. There were some discussions regarding that contract.

Data Review

The only contaminated media at the Site is groundwater. There is no risk to human health or the environment from surface water, sediments or soil. Vapor intrusion is also not an issue as there is no VOC contaminated plume beneath any homes as discussed in the 2012 report cited in the 2013 FYR.[3]

The ROD set Interim Cleanup Levels (ICLs) for the Site that were updated in the 1998 Amended ROD and are shown in Table 1 of Appendix B. Groundwater contamination is restricted to the 1.9 acre Site and a small area north of the Site property boundary. VOCs meet the current ICLs in the overburden groundwater while arsenic and manganese exceed ICLs but at relatively low concentrations. In bedrock groundwater, VOCs, arsenic and manganese exceed ICLs.

The overburden aquifer is only contaminated with arsenic and manganese. Arsenic and manganese exceed ICLs at concentrations that are within an order-of-magnitude of those ICLs. There is no discernable trend in metal concentrations since the 2013 FYR. Concentrations, as shown in Appendix B, appear to be driven by water levels or other geochemical conditions and can vary greatly in the same well at different times of the year. Generally, concentrations are declining for arsenic, the high concentration of arsenic in 2013 was 80.4 micrograms per liter (µg/L) and in 2016 was 55 µg/L. It is believed that occurrences of both arsenic and manganese are produced from geochemical processes between the groundwater, the organic materials dissolved in groundwater and the aquifer matrix. It is expected that ICLs and protective concentrations will be met for arsenic and manganese in the future as the aquifer returns to ambient conditions. Ambient conditions are those that existed before the organic contamination, that is an oxygenated groundwater environment. Once the remaining organic contaminants are destroyed either through natural processes or by an active groundwater remedy, it is expected that the aquifer will become increasingly oxygenated and return to ambient conditions.

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[3] Arcadis, *Vapor Intrusion Evaluation, Tibbetts Road Site, Barrington, New Hampshire*, February 28, 2012.

In bedrock groundwater, arsenic, manganese, the non-chlorinated organic contaminant, benzene, and the VOCs trichloroethylene (TCE) and cis-1,2-dichloroethylene (1,2-DCE) are the only contaminants exceeding ICLs. All are either close to the property bounds of the Site or just north of the Site, and relatively low in concentration. Table 3 in Appendix B (page 38) provides summary statistics for the three contaminants. Benzene exceeded ICLs in 11 of 39 sampling intervals, with the highest concentration at 152 µg/L. This exceeds the ICL of 5 µg/L significantly, but the next highest occurrence is 42 µg/L and the remaining 9 occurrences are at much lower concentrations. TCE exceeded ICLs in 3 of 39 locations (ICL = 5 µg/L) with the highest concentration at 97.7 µg/L and the other two concentrations less than 10 µg/L. 1,2-DCE exceeded ICLs (70 µg/L) in 5 of 39 locations with the highest concentration at 190 µg/L, and the remaining four wells significantly lower in concentration. These numbers do not agree with Table 4 in the 2016 Annual Report produced by Arcadis because those results include monitoring in wells that were undergoing extraction during the Directed Groundwater Recirculation (DGR) pilot. Including the wells whose objective was to extract contaminants may bias results to appear higher in concentration than in non-pumping conditions.

Overall, concentrations of organic contaminants continue to decline but will take additional time in the bedrock aquifer. Monitoring should continue, but the analytes and frequency may need to be examined to determine a more efficient means of monitoring to discern trends and conditions that affect contaminants. Appendix B examines the trends of contamination in bedrock groundwater which may be summarized as follows:

- TCE and 1,2-DCE are the only chlorinated VOCs above ICLs (5 and 70 µg/L, respectively) and Benzene is the only non-chlorinated organic contaminant to exceed its ICL (5 µg/L). Comparisons of data between 2013 and 2016 may have been influenced by the proximity of the injection and extraction wells for the DGR system to the monitoring wells, but monitoring was done so as to minimize its influence, and the following observations for each of the contaminants can be made:
    - Benzene decreased in concentration from 365 µg/L to 152 µg/L from 2013 to 2016 in well 203R, the well with the highest benzene concentration.
    - Trichloroethylene increased in concentration from 79.5 to 97.7 µg/L from 2013 to 2016 in well 67R (the well with the highest concentrations).
    - 1,2-Dichloroethylene decreased in concentration from 238 to 142 µg/L from 2013 to 2016 in well 203R.
- Arsenic and manganese are likewise difficult to assess due to the changing conditions that resulted from the performance of the pilot test that injected oxygen, as well as recirculated groundwater, between the three general intervals in the bedrock aquifer. Generally, as shown in Table 3 of Appendix B, the concentration of arsenic has increased, but its frequency has declined. Meanwhile, manganese declined in concentration but that may be the result of continued recovery from the addition of potassium permanganate to the bedrock aquifer in 2008. It is believed that the same processes that have elevated arsenic and manganese in overburden groundwater exist in bedrock and that conditions will recover as organic contamination declines and the groundwater environment becomes less reducing and returns to ambient conditions.

The data are discussed in greater detail in Appendix B.

Site Inspection

The inspection of the Site was conducted on 4/10/2018. In attendance were Darryl Luce, EPA, and Kenneth Richards, NHDES. The purpose of the inspection was to assess the protectiveness of the remedy. It was noted that a shed at the northern boundary of the Site property was in disrepair. This shed housed equipment used during the injection and DGR pilot tests. During the April 10 meeting with Arcadis, described above, this was mentioned and Mr. Sullivan said that the shed would be removed and the equipment housed in a garage on the Site. No issues impacting the current or future protectiveness were identified.

V. TECHNICAL ASSESSMENT

QUESTION A: Is the remedy functioning as intended by the decision documents?

YES – The PRP performed the active components of the cleanup remedy as described in the ROD: construction and operation of a VER system, expansion of the alternate water supply, establishment of institutional controls, and disposal of remaining drums stored at the Site. The Amended ROD changed the groundwater remedy to bioremediation and phytoremediation which the PRP implemented.

The bioremediation and phytoremediation remedies continue to function at the Site with metal concentrations in the overburden groundwater declining in response to a slow return to ambient groundwater conditions. The present remedy uses no mechanical equipment, only the natural native microbial flora and the remaining poplar trees. The remaining poplar trees, only 100 to 200 of the original 1,600, 3-foot high whips remain, are now at least 18 years old and many are over 40-feet in height.

Groundwater monitoring results indicate that the current remedy is functioning as intended and concentrations are declining; however, the restoration timeframe to attain the ICLs in the 1998 AROD will take longer than anticipated. The 1998 AROD had predicted the attainment of ICLs for organic contaminants in overburden groundwater by 2012. Essentially, ICLs have been attained for the organic contaminants in overburden groundwater as shown in Appendix B. No prediction was made for restoration of metal concentrations in groundwater in the 1998 AROD. Nor was a prediction made for bedrock contaminants due to the nature of bedrock. Bedrock contamination still consists of both organic and metal contaminants.

Contaminated groundwater is not migrating. In bedrock groundwater, reductions in organic contaminants have occurred. The trends seen in the groundwater for the Site for inorganic contaminants, primarily arsenic and manganese, are not as clearly evident at this time.

Institutional Controls prevent contact with contaminated groundwater through a Zoning Ordinance passed by the Town of Barrington in 2014. Compliance with the ordinance is strongly monitored by the SLVWD because of its concern with cross-connections and back-feeding of untreated water into the system. All homeowners that use the system are notified of the prohibition on extracting groundwater on an annual basis by the SLVWD in literature and through an annual meeting.

QUESTION B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of the remedy selection still valid?

NO – There have been some changes in exposure assumptions, toxicity factors, regulatory limits, and risk assessment methodology. However, data provided in Appendix B indicate that there has been no change in Site conditions which would warrant a re-evaluation of risk because exposure to groundwater is being prevented and because excavated soils have been replaced by clean fill, which has been planted with grass and poplar trees.

In February 2002, after the 1992 ROD and 1998 AROD were issued, EPA revised the MCL for arsenic from 50 µg/L to 10 µg/L. This will likely further extend the estimated timeframe for reaching cleanup goals. This change will not affect the risk calculated at the Site; however, it is a relevant and appropriate requirement that must be met. Table 2 on page 11 details the change in MCL.

The 1992 ROD established an ICL of 3,650 µg/L for dissolved manganese in groundwater based on human consumption over a 30-year period. That ICL was retained in the 1998 AROD. However, based on current toxicity information, the protective cleanup level for manganese is 300 µg/L (EPA Drinking Water Health Advisory).

The risk-based ICL for 4-methyl-2-pentanone (synonym: methyl isobutyl ketone) is 1825 µg/L, which was based on a hazard quotient (HQ) of 1 for residential tap-water use. Due to a decrease in non-cancer toxicity, the risk-based cleanup level would increase to 6260 µg/L for a HQ of 1.

The risk-based ICL for naphthalene is 1460 µg/L based on a HQ of 1. Naphthalene is now considered to have a higher non-carcinogenic toxicity, as well as carcinogenic effects. As a result, the risk-based concentrations would now be 6.11 µg/L for a HQ of 1 and 0.165 µg/L for a cancer risk of 1E-06. EPA's maximum risk limits of HQ of 1 or cancer risk of 1E-04 would be attained at 6.11 µg/L.

The risk-based ICL for vanadium is 256 µg/L based on an HQ of 1. Vanadium is now considered to have a higher non-cancer toxicity. As a result, the risk-based concentration would now be 86 µg/L for a HQ of 1. Other recommended changes to the ICLs include the following:

- The ICL for nickel is based on an MCL of 100 µg/L. There is currently no MCL for nickel, and the risk based ICL would be 392 µg/L for a HQ of 1.
- The ICL for bis(2-ethylhexyl)phthalate (BEHP) is 4 µg/L based on the prior MCL. The current MCL is 6 µg/L.
- The ICL for toluene is 1000 µg/L based on the prior MCL. The current MCL is 10,000 µg/L.

EPA will need to prepare the appropriate decision document to formally document these changes to the 1992 ROD and 1998 AROD. The progress of groundwater remediation will be assessed by comparison with the resulting updated groundwater standards and risk-based concentrations.

Changes in Toxicity and Other Contaminant Characteristics

- **2012 Perchloroethylene (PCE)** cancer and non-cancer toxicity values

On February 10, 2012, EPA finalized the cancer and non-cancer toxicity values for PCE. These new values indicate that PCE is now more toxic from cancer health effects but less toxic from non-cancer hazard effects. These toxicity changes would result in an increased cancer risk and a decreased non-cancer hazard from exposure to PCE. This change does not affect protectiveness because the cleanup level is based on the MCL, not risk.

- **2016 Lead** in Soil Cleanups

EPA's 2016 OLEM memorandum "Updated Scientific Considerations for Lead in Soil Cleanups" (OLEM Directive 9200.2-167) indicates that there is sufficient evidence that adverse health effects are associated with blood lead levels (BLLs) at less than 10 µg/dL. The memorandum mentioned that several studies have observed "clear evidence of cognitive function decrements in young children with mean or group BLLs between 2 and 8 µg/dL." Any soil screening, action or cleanup level developed based on the previous BLL of 10 µg/dL (provide specific action or cleanup level as presented in the ROD) may not be protective.

EPA's approach to evaluate potential lead risks is to limit exposure to residential and commercial soil lead levels such that a typical (or hypothetical) child or group of similarly exposed children would have an estimated risk of no more than 5% of the population exceeding a 5 microgram per deciliter (µg/dL) blood lead level (BLL). This is based on updated scientific information and is in agreement with the Lead Technical Review Workgroup's current support for using a BLL of 5 µg/dL as the level of concern in the Integrated Exposure Uptake Biokinetic Model (IEUBK) and Adult Lead Methodology (ALM). A target BLL of 5 µg/dL reflects current scientific literature on lead toxicology and epidemiology that provides evidence that the adverse health effects of lead exposure do not have a threshold.

EPA's 2017 OLEM memorandum "Transmittal of Update to the Adult Lead Methodology's Default Baseline Blood Lead Concentration and Geometric Standard Deviation Parameters" (OLEM Directive 9285.6-56) provides updates on the default baseline blood lead concentration and default geometric standard deviation input parameters for the Adult Lead Methodology. These updates are based on the analysis of the NHANES 2009-2014 data, with recommended updated values for baseline blood lead concentration being 0.6 µg/dL and geometric standard deviation being 1.8.

Using updated default IEUBK and ALM parameters at a target BLL of 5 µg/dL, site-specific lead soil screening levels (SLs) of 200 parts per million (ppm) and 1,000 ppm are developed for residential and commercial/industrial exposures, respectively. These changes do not affect protectiveness because the excavated soils were replaced with clean fill, and the area of excavation was planted with grass and hundreds of poplar trees.

- **Polycyclic Aromatic Hydrocarbons (PAHs)** cancer and non-cancer toxicity values

On January 19, 2017, EPA issued revised (less carcinogenic) cancer toxicity values and new non-cancer toxicity values for benzo(a)pyrene. Benzo(a)pyrene did not have non-cancer toxicity values prior to January 19, 2017. Benzo(a)pyrene is now considered to be carcinogenic by a mutagenic mode of action; therefore, cancer risks must be evaluated for different human developmental stages using age dependent potency adjustment factors (ADAFs) for different age groups. The cancer potency of other carcinogenic PAHs is adjusted by the use of relative potency factors (RPFs), which are expressed relative to the potency of benzo(a)pyrene. The non-cancer effects of benzo(a)pyrene were not evaluated in the past due to the absence of non-cancer values. This change does not affect protectiveness because exposure to contaminated groundwater is prevented, and the excavated soils were replaced with clean fill, and the area of excavation was planted with grass and hundreds of poplar trees.

- **2016 Perfluorooctanic acid and Perfluorooctanesulfonic acid (PFOA/PFOS)** non-cancer toxicity values

In May 2016, EPA issued final lifetime drinking water health advisories for PFOA and PFOS, which identified a chronic oral reference dose (RfD) of 2E-05 mg/kg-day for PFOA and PFOS (USEPA, 2016a and USEPA, 2016b). These RfD values should be used when evaluating potential risks from ingestion of contaminated groundwater at Superfund sites where PFOA and PFOS might be present based on site history. Potential estimated health risks from PFOA and PFOS, if identified, would likely increase total site risks due to groundwater exposure. Further evaluation of potential risks from exposure to PFOA and PFOS in other media at the Site might be needed based on site conditions and can also affect total site risks. PFOA/PFOS in groundwater have not been measured at the Site, but will be measured during the next five year review period.[4]

- **2014 Perfluorobutanesulfonic acid (PFBS)** non-cancer toxicity value

PFBS has a chronic oral RfD of 2E-02 mg/kg-day based on an EPA Provisional Peer Reviewed Toxicity Value (PPRTV) (USEPA, 2014a). This RfD value should be used when evaluating potential risks from ingestion of contaminated groundwater at Superfund sites where PFBS might be present based on site history. Potential estimated health risks from PFBS, if identified, would likely increase total site risks due to groundwater exposure. Further evaluation of potential risks from exposure to PFBS in other media at the Site might be needed based on site conditions and can also affect total site risks. PFBS in groundwater have not been measured at the Site, but will be measured during the next five year review period.

Changes in risk assessment methods:

- 2014 OSWER Directive Determining Groundwater Exposure Point Concentrations, Supplemental Guidance

In 2014, EPA finalized a Directive to determine groundwater exposure point concentrations (EPCs) http://www.epa.gov/oswer/riskassessment/pdf/superfund-hh-exposure/OSWER-Directive-9283-1-42-GWEPC-2014.pdf
This Directive provides recommendations to develop groundwater EPCs. The recommendations to calculate the 95% UCL of the arithmetic mean concentration for each contaminant from wells within the core/center of the plume, using the statistical software ProUCL, could result in lower groundwater EPCs than the maximum concentrations routinely used for EPCs as past practice in risk

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[4] After a review of USEPA's information, NHDES filed an emergency rule on May 31, 2016 to establish the health advisories for PFOA and PFOS as Ambient Groundwater Quality Standards (AGQS).

assessment, leading to changes in groundwater risk screening and evaluation. In general, this approach could result in slightly lower risk or lower screening levels. (Reference: USEPA. 2014. Determining Groundwater Exposure Point Concentrations. OSWER Directive 9283.1-42. February 2014.). This change does not affect protectiveness because groundwater exposure is prevented.

- 2014 OSWER Directive on the Update of Standard Default Exposure Factors

In 2014, EPA finalized a Directive to update standard default exposure factors and frequently asked questions associated with these updates. http://www.epa.gov/oswer/riskassessment/superfund_hh_exposure.htm (items # 22 and #23 of this web link). Many of these exposure factors differ from those used in the risk assessment(s) supporting the ROD(s). These changes in general would result in a slight decrease of the risk estimates for most chemicals. (Reference: USEPA. 2014. Human Health Evaluation Manual, Supplemental Guidance: Update of Standard Default Exposure Factors. OSWER Directive 9200.1-120. February 6, 2014.). This change does not affect protectiveness because groundwater exposure is prevented, and excavated soils were replaced by clean fill, with planting of grass and poplar trees.

- 2012 OSWER Directive on Recommendations for Default Value for Relative Bioavailability of Arsenic in Soil

Based on a compilation and review of data on relative bioavailability of arsenic in soil in 2012, arsenic was found to be less bioavailable via soil ingestion relative to other analytes. A default value of relative bioavailability (RBA) of 60% is now applied during soil/sediment ingestion calculations of risk/cleanup levels. This default RBA value reduces arsenic contribution to risk and/or increases arsenic cleanup levels (Reference: USEPA. 2012. Compilation and Review of Data on Relative Bioavailability of Arsenic in Soil and Recommendations for Default Value for Relative Bioavailability of Arsenic in Soil Documents. OSWER Directive 9200.1-113. December 31, 2012.). This change does not affect protectiveness because the excavated soils were replaced by clean fill, with planting of grass and poplar trees.

- Most current RSLs tables

Updated twice/year. Use most up-to-date tables as available at: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/

- Most current VISLs tables

Updated periodically. Use most up-to-date tables as available at: http://www.epa.gov/oswer/vaporintrusion/guidance.html#Item6

QUESTION C: Has any **other** information come to light that could call into question the protectiveness of the remedy?

NO.

Technical Assessment Summary

Arsenic and manganese are present in both the overburden and bedrock groundwater. These elevated concentrations are likely the result of altered environmental conditions causing natural arsenic and other metals to dissolve from the aquifer matrix.[5] It is expected that as conditions in the aquifer return to their natural state, the present reducing environment will become an oxidizing environment and the metals will precipitate and not pose a risk. Bedrock VOC groundwater contamination is limited to an area north of the property boundary.[6]

Although active groundwater remedial efforts have greatly reduced contaminant concentrations in the overburden and bedrock groundwater, additional monitoring is required to determine trends. Future risk may occur if contaminated groundwater is used for drinking water purposes; however, ICs are in place and prevent the use of groundwater. A detailed analysis of Site conditions is presented in Appendix B.

VI. ISSUES/RECOMMENDATIONS

The five issues identified in the 2013 FYR are described in Table 1 on page 7 of this document. Four of those five issues were completed and are resolved. The remaining issue: #4 – *Bedrock groundwater high concentrations of contaminants*, will continue to be addressed through monitoring and a Directed Groundwater Recirculation pilot test.

Issues and Recommendations Identified in the 2018 Five-Year Review:

OU(s):	**Issue Category:** Remedy Performance. **Note**: This issue was cited in the 2013 Five-Year Review, issue #4, a Directed Groundwater Recirculation pilot test that began in 2014.			
	Issue: Bedrock groundwater VOC contaminants exceed ICLs.			
	Recommendation: Continue the pilot program testing treatments and different extraction/injection geometries.			
Affect Current Protectiveness	**Affect Future Protectiveness**	**Party Responsible**	**Oversight Party**	**Milestone Date**
No	Yes	PRP	EPA/State	6/30/2022

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[5] Hounslow, A.W. *Ground-water geochemistry: arsenic in landfills.* Ground Water 18: 331-333 (1980).

[6] *Evaluation of Current Biogeochemical Conditions and Applicability of Monitored Natural Attenuation*, Tibbetts Road Site…December 2007 (ARCADIS: Lowell, MA) p. 5 – 13.

OU(s):	**Issue Category:** Monitoring. **Note**: Potential presence of PFAS.			
	Issue: It is unknown if Perfluorobutanesulfonic acid, Perfluorooctanic acid or Perfluorooctansulfonic acid were released at the Site.			
	Recommendation: Include per- and polyfluorinated substances that include PFOA, PFOS and PFBS in an upcoming groundwater monitoring event to determine if these compounds are associated with the Site.			
Affect Current Protectiveness	**Affect Future Protectiveness**	**Party Responsible**	**Oversight Party**	**Milestone Date**
No	Yes	PRP	EPA/State	6/30/2019

Other Findings

- Contaminants in Overburden groundwater (metals) and Bedrock groundwater (metals and VOCs) remain above cleanup levels. It will be necessary to continue groundwater sampling.
- The Institutional Control, a Zoning Bylaw, prevents exposure to groundwater contaminants. It will be necessary to continue monitoring and enforcement of the Town's Bylaw by the Swains Lake Village Water District and the PRP.
- The ICLs set for arsenic and manganese in the 1992 ROD, 50 and 3,650 µg/L, respectively, must be evaluated against background concentrations and updated within a decision document.
- The 1998 Amended ROD predicted that MNA would succeed in attaining ICLs for VOCs by 2012 and that inorganic contaminants, arsenic and manganese, would attain ICLs "shortly" thereafter. Although ICLs for VOCs have been attained in the Overburden aquifer, inorganic contaminants still exceed ICLs in Overburden groundwater and Bedrock groundwater has not met ICLs for either VOCs and inorganics. Therefore, it will be necessary to develop revised estimated cleanup times for arsenic and manganese in overburden groundwater and, in bedrock groundwater, for arsenic, manganese, VOCs and benzene.

VII. PROTECTIVENESS STATEMENT

Sitewide Protectiveness Statement
Protectiveness Determination: Short-term Protective
Protectiveness Statement: The remedial actions taken are protective of human health and the environment in the short-term because there are no completed exposure pathways, Institutional Controls are in place and monitored, and groundwater monitoring continues to ensure that migration does not occur. To be protective in the long-term, monitoring must include sampling for PFOA, PFOS and PFBS contaminants; evaluating additional measures to reduce bedrock groundwater concentrations using Directed Groundwater Recirculation; and implementing those that are successful.

VIII. NEXT REVIEW

The next five-year review report for the Tibbetts Road Superfund Site is required five years from the completion date of this review.

APPENDIX A – REFERENCE LIST

ARCADIS, Geraghty & Miller, Inc., Andover, MA , June 1997, *Final Remedial Action Construction Report for Overburden Remedial System, Tibbetts Road.*

ARCADIS, Geraghty & Miller, Inc, Andover, MA, July 1997, *Findings of Subsurface Investigation, Tibbetts Road Site*.

ARCADIS, Lowell, MA, December 1998, *Phytoremediation Installation Report, Tibbetts Road Site*.

ARCADIS, Lowell, MA, December 2007, *Evaluation of Current Biogeochemical Conditions and Applicability of Monitored Natural Attenuation, Tibbetts Road Site*.

ARCADIS, Lowell, MA, April 2008, *Vapor Intusion Evaluation, Tibbetts Road Superfund Site, Barrington, NH.*

ARCADIS, Lowell, MA, May 6, 2008, *In-situ Chemical Oxidation Pilot Testing, Tibbetts Road Site, Barrington, New Hampshire*.

ARCADIS, Chelmsford, MA, February 28, 2012. *Vapor Intrusion Evaluation, Tibbetts Road Site, Barrington, New Hampshire*.

ARCADIS, Chelmsford, MA, May 2013. *Summary of Environmental Monitoring 2012, Tibbetts Road Site, Barrington, New Hampshire*.

Emery & Garrett Groundwater, Inc., Meredith, NH, June 2011. *Draft Final Report For New Small Production Wells For Small Community Water Systems, Swains Lake Village Water District, Barrington, New Hampshire*.

CDM Federal Programs Corporation, Boston, MA, June 1992, *Remedial Investigation Report Tibbetts Road Superfund Site.*

Civil Action C-91-120-S, C-91-194-S, Lodged 11/8/1994 and entered 3/20/1995, *Consent Decree, United States of America and State of New Hampshire, Plaintiffs v. Ford Motor Company, Defendant.*

Hounslow, A.W., 1980, *Ground-water geochemistry: arsenic in landfills*. Groundwater 18: 331-333.

Lyons, J.B., Bothner, W.A., Moench, R.H., and Thompson, J.B., Jr., 1997. *Bedrock Geologic Map of New Hampshire.* United States Geological Survey.

New Hampshire Department of Environmental Services. 2006. *NHDES Risk Characterization and Management Policy (Section 7.4(5)) Method 1 Groundwater Standards* (Ambient Groundwater Quality Standards).

U.S. Environmental Protection Agency: Region 1, Boston, September 29, 1992, *Record of Decision, Tibbetts Road Superfund Site.*

U.S. Environmental Protection Agency. July 30, 1996b. *Low Stress (low flow) Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells.* Revision 2.

U.S. Environmental Protection Agency: Region 1, Boston, September 28, 1998, *Amended Record of Decision, Tibbetts Road Superfund Site.*

U.S. Environmental Protection Agency: Region 1, Boston, September 29, 1998, *Preliminary Closeout Report, Tibbetts Road Superfund Site.*

U.S. Environmental Protection Agency. March 2001. *EPA Requirements for Quality Assurance Project Plans (EPA QA/R5).*

U.S. Environmental Protection Agency. September 28, 2003. *Five-Year Review Report. First Five-Year Review Report for the Tibbetts Road Superfund Site, Town of Barrington, Strafford County, New Hampshire.*

APPENDIX B – SITE BACKGROUND AND TECHNICAL ASSESSMENT

Technical Assessment of Contaminant Status

Tibbetts Road Superfund Site, Barrington, New Hampshire
August 2018

Introduction

This appendix describes contamination at the Site, controlling factors in contaminant transport and fate, and progress towards meeting Interim Cleanup Levels (ICLs).

Physical Characteristics Of The Site And Surrounding Area

Physical Setting

The Tibbetts Road Superfund Site (the "Site") is located in the Town of Barrington, Strafford County, southeastern New Hampshire, 43° 10' 46" N and 71° 02' 01" W. The 1.9-acre Site is owned by the estate of Alexander Johnson, and is bordered by Tibbetts Road to the southwest, and by residences on the remaining three sides.

The Site is in an area of light, rural residential development. The area was formerly logged and farmed for a number of years prior to residential development that began in the late 1970s. Except for the landscaped pockets surrounding each residence, the area consists of oak-maple-white pine forest. At the southern end of Tibbetts Road is the entry to the 1,435-acre Samuel A. Tamposi Water Supply Reserve Conservation Land (the "Tamposi Property"). This property is protected from future development by a conservation easement held by the Society for the Protection of New Hampshire Forests[7,8] The Tamposi property consists of wetlands and mixed hardwood and conifer forest and is set aside for passive recreation and watershed protection. Swains Lake lies 800 feet north of the Site. Figure 1 shows the location of the Site relative to the surrounding features.

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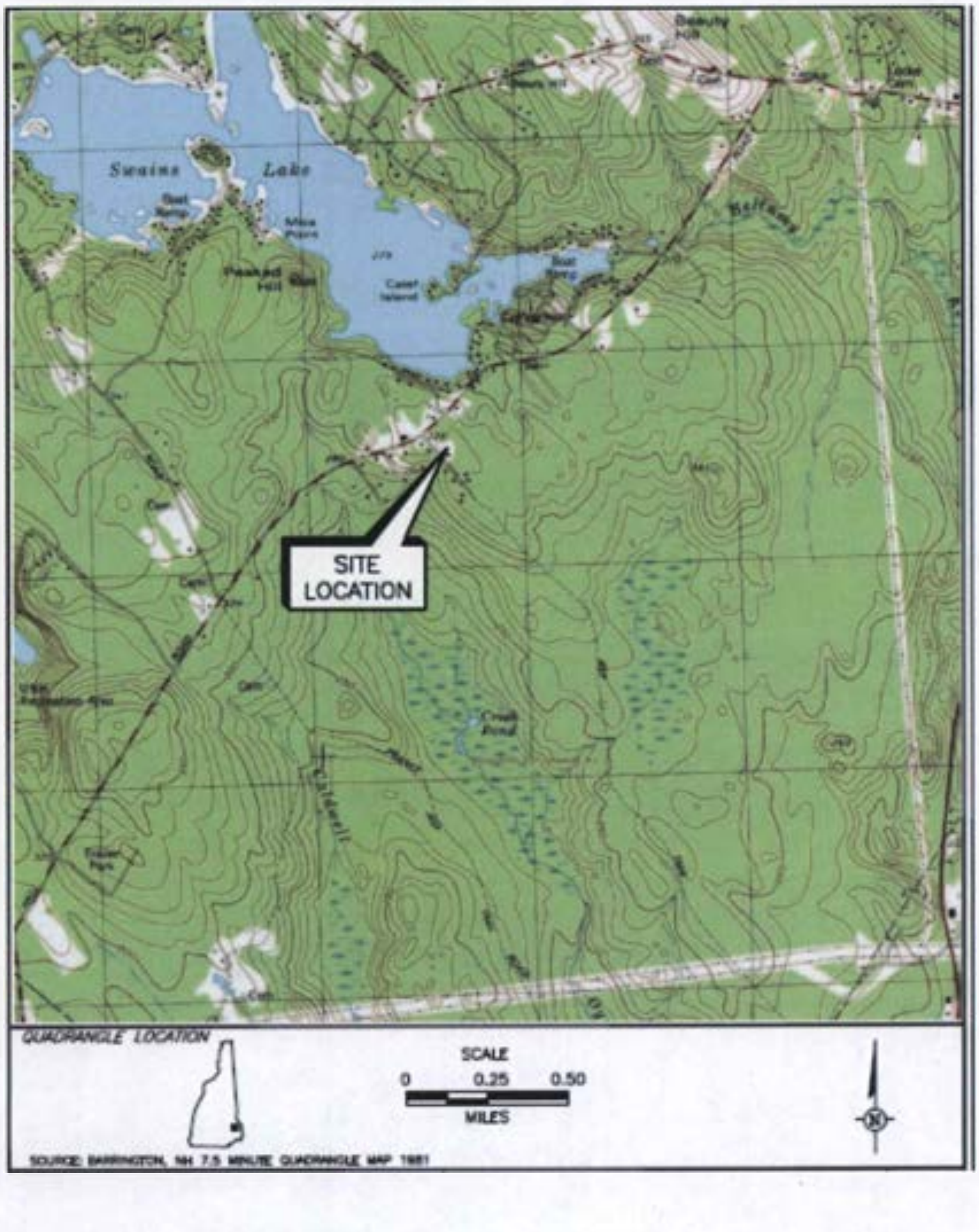
[7] Fosters Daily Democrat, Wednesday, January 18, 2012.

[8] http://barringtonconcom.org/6._Samuel_A._Tamposi_Water_Supply_Reserve_%28SATWaSR%29_Main_Page.html , accessed on May 1, 2013.

Figure 1: Site Location Map. The topographic map shows the location of the Site relative to the State and surrounding features. The datum is from 1981 and ARCADIS altered the base of this document to supply the locus map and the scale information. The Site is located at 43° 10' 46" N and 71° 02' 01" W. The black lines superimposed on the topographic map are spaced at 1 kilometer intervals.



SOURCE: BARRINGTON, NH 7.5 MINUTE QUADRANGLE MAP 1981

Site Conditions

Currently, the 1.9 acre Johnson property exists as a vacant lot and has a driveway, a small garage, a large sugar maple at the front of the lot, and a large number of poplar trees. The poplar trees are part of the phytoremediation remedy completed in 1998. Arcadis maintains the property. Figure 2 shows the features of the Site.

Figure 2: Site Features. The aerial photograph from GoogleEarth Pro, on the upper right, shows the Site and neighborhood as they appeared in 2006, and is virtually unchanged since that time. Various features are identified including the location of Swains Lake, the drinking water treatment plant and the road network. In the aerial, the property boundaries of the Site are evident by the change in vegetation. The line drawing to the lower left, prepared by ARCADIS, shows the Site in greater detail, the property line (enclosing 1.9 acres), the location of the nearby homes, a portion of the monitoring well network, and the location of three former drum storage areas (shaded). There are no surface water bodies on the Site.

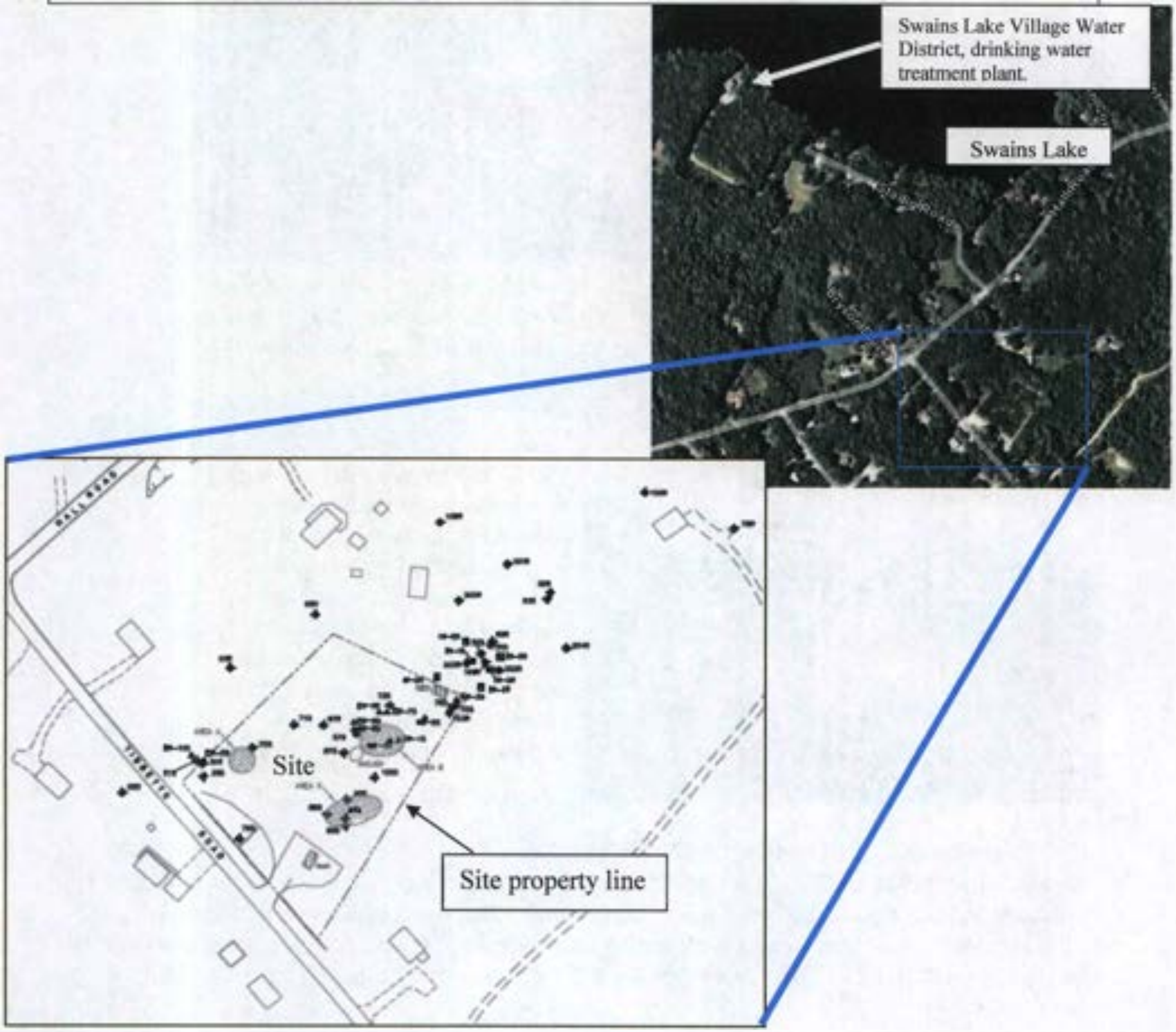


Photo 1 shows the former Johnson residence in 1995 during construction of the overburden remedy. Photo 2 shows the Site in 1998 during the remedy operation.

Photo 1: The front of the Site bordering Tibbetts Road and the home, an original post-and-beam, of Alexander Johnson in 1995. The home was demolished as part of the remedy to seal the ground surface for vacuum extraction. The stone wall and large Sugar Maple remain as of 2018.

Photo 2: The Site after paving to prevent air infiltration during vacuum extraction. The photo was taken standing where the original house stood and looking north. The pavement was removed and 1,600 poplar trees were planted in this area after the vacuum extraction remedy attained its objectives in 1998.

Surrounding Properties, Condition and Use

The area surrounding the Site is zoned for residential use although one home at the end of Tibbetts Road has an attached auto paint shop. During the period of Site characterization and active remediation no new homes were built within ½ mile of the Site. After 2008, a residential open space subdivision, Cedar Creek (formerly Sera Lane), consisting of 18 single-family homes, began construction at the end of Tibbetts Road, 600 feet south of the Site. As of April 2018, seventeen of the 18 homes have been built.

Surface Water Hydrology

The Site straddles a ridge that runs northwest towards Swains Lake. The ridge serves as a drainage divide between the Oyster River to the south and the Bellamy River to the north. Figure 3 shows the Site in plan view and cross section. Surface water generally infiltrates the overburden aquifer and becomes part of the groundwater. The nearest waterbody is a small wetland, not shown on Figure 1, that lies approximately 600 feet north of the Site and drains westward to Swain's Lake. Swains Lake, which is 800 feet north of the Site, is the result of a shallow impoundment and overflows into the Bellamy River at its eastern end. There are no significant surface water bodies in the Oyster River watershed south of the Site shown on Figure 1 except Creek Pond, approximately 1 mile south of the Site.

Geology

Overburden geology at the Site consists of a 15 to 25 feet thick layer of mixed sands and gravels, glacial till. The glacial till rests on top of a lens of compacted clay known as a "lodgment till" that is more than 30 feet thick and acts as an aquiclude. The lodgment till pinches out just beyond the northern and southern property bounds of the Site. The lodgment till is underlain by a fractured granite bedrock. This bedrock is more precisely described as a quartz-monzonite (5 to 20% quartz and 35 to 65% alkali and plagioclase feldspar).[9] The bedrock fractures consist of many sub-horizontal release fractures in the upper, weathered sections that connect to steeply dipping fractures that are oriented roughly northeast-southwest and northwest-southeast.[10] Figure 3 has a cross-section that shows the geology beneath the Site in schematic form.

Hydrogeology

Surface water infiltrates into the overburden aquifer. The overburden groundwater flow mirrors the surface topography, resulting in northward and southward flows of groundwater. The overburden groundwater flows laterally to the edge of the lodgment till as shown in Figure 3 and downward into the weathered bedrock.[11]

Groundwater then enters the weathered bedrock through a combination of sub-horizontal and steeply dipping fractures. The fracture flow extends over considerable distances and can be significant in volume.[12] Pump tests in well 76R, during the Remedial Investigation, found an estimated yield of 400 gallons per minute. Domestic wells typically found productive fractures 300 feet below ground surface and generally produce 20 to 70 gallons per minute. Overall though, fracture flow is unpredictable, many bedrock wells in Cedar Creek do not yield high volumes, perhaps due to the steep dip of the main fractures. Figure 3 also generalizes the groundwater flow at the Site.

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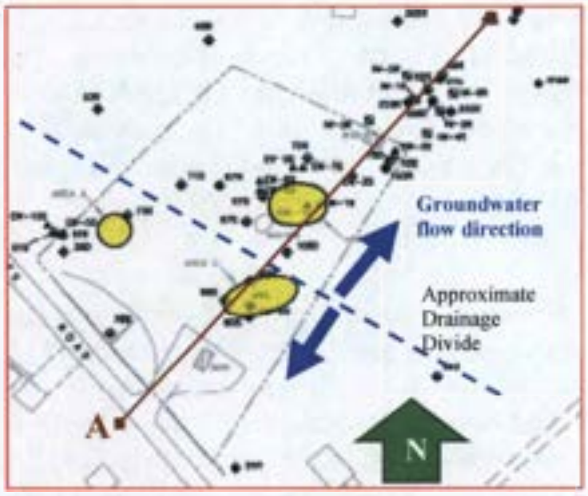
[9] *Remedial Investigation Report Tibbetts Road Superfund Site, Volume I*, June 1992 (CDM Federal Programs Corporation, Boston, MA) p. 3-1 to 3-2.

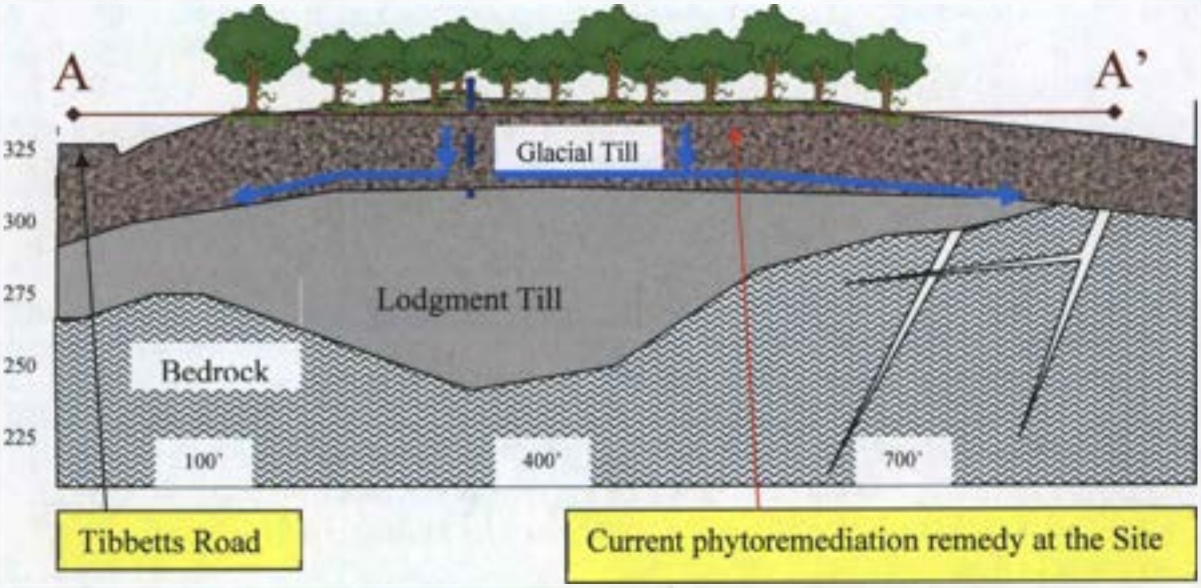
[10] *Remedial Investigation, Volume I*, p. 3-7 to 3-11.

[11] *Remedial Investigation, Volume I*, p. 3-5 to 3-6.

[12] *Remedial Investigation, Volume I*, p. 3-10 to 3-23.

Figure 3: Site Geology and Groundwater Flow
Site geology consists of three primary units depicted in the cross-section below. The first diagram shows the location of the drainage divide (dashed blue line), the cross-section (solid brown line with labels A at the southwest end and A' at the northeast end), and where groundwater generally flows in the overburden aquifer (thick blue arrows).





Cross Section A-A' showing generalized topography, geology, and groundwater flow. Elevation on the left is above mean sea level. The fractures depicted in the bedrock are schematic

Resource Use

Groundwater and surface water constitute important resources to the surrounding community. With the exception of the area surrounding the Site, drinking water is supplied only by private wells in bedrock aquifers. Water supply to the area surrounding the Site is described in the following Section, History of Contamination and Remedial Action.

The many lakes, ponds and streams in the area are also important recreational resources in Barrington. Swains Lake is classified as a class "B" waterway by the State of New Hampshire and is used for recreational swimming, boating and fishing. A seasonal campground, approximately 1 kilometer north of the Site, lies on the eastern shore of Swains Lake. Swains Lake is ringed by many large homes that were converted from seasonal cottages. Swains Lake is also a tributary to the Bellamy River which eventually forms the Bellamy Reservoir, a primary drinking water resource for the city of Portsmouth, New Hampshire.

History Of Contamination And Remedial Actions

Originally, the property and much of the surrounding area was one property that contained a single family residence belonging to Mr. Alexander "Bud" Johnson. It is reported that from 1945 until 1958 Mr. Johnson transported drums to his property for storage and use. These drums contained wastes from industrial processes, primarily automobile painting. Mr. Johnson stored these drums in three areas shown as yellow circles on the plan view of Figure 3.

Mr. Johnson began selling house lots from the original property in the 1970s. The new neighbors noticed the stockpile of drums, observed materials leaking from the drums, and notified the State of New Hampshire. During an initial investigation of the Site by State of New Hampshire personnel in 1982, it became apparent that the drums contained hazardous materials and had leaked onto the ground. Subsequent testing of the drums showed the presence of Volatile Organic Compounds (VOCs) such as acetone, toluene, benzene, xylene, trichloroethylene (TCE), tetrachloroethylene (PCE), 4-methyl-2-pentanone (also known as methyl isobutyl ketone or MIBK), and polychlorinated biphenyls (PCBs).

Initial Responses

Drum Removal

In 1984, the EPA, acting at the request of the State of New Hampshire, temporarily relocated the surrounding residents and removed 337 drums from the property that contained solvents, PCBs and other hazardous materials. During the removal, EPA determined that the underlying soil was contaminated and that contamination of the groundwater was likely. Figures 2 and 3, above, show the location of the drum storage areas as hatched and yellow circles, respectively.

Soil Removal

Following a 1986 investigation into the extent of soil and groundwater contamination, EPA and the State of New Hampshire excavated over 405 yards of soil contaminated with solvents, PCBs, and other organic compounds in drum storage areas B and C to a depth of approximately 6 feet. The soil was removed from the Site and disposed at a secure landfill. An additional 3.5 cubic yards of soil contaminated with the dioxin 2,3,7,8 TCDD was retained at the Site and destroyed in a mobile incinerator. The 3.5 cubic yards of soil were placed into twelve 55-gallon drums following on-site treatment and later disposed in a secure landfill. The areas of soil removal were backfilled with clean fill from an off-site source.[13] Former drum storage Area A (the western-most of the three areas) did not have concentrations of soil contaminants that required removal.

Drinking Water Treatment Plant and Distribution System

At the time of EPA's initial response, all residents in Barrington, New Hampshire obtained drinking water through individual bedrock wells. Groundwater sampling indicated that Site contaminants were entering the residential wells and the concentrations were above those protective of human health.[14] In response to this contamination, EPA began construction of a drinking water treatment plant. EPA finished building the treatment plant and distribution system in 1988. The plant initially served 45 homes that were affected by the contamination. After one year of system shake-down EPA turned the treatment plant over to the State. The State then turned it over to a group of residents in the affected area. Those residents formed the Swains Lake Village Water District (SLVWD) to operate the drinking water treatment plant. As part of the 1995 Consent Decree (1995 CD), the SLVWD and the PRP agreed to fund and continue to operate the treatment plant. To prevent the use of groundwater in areas where groundwater was contaminated, the SLVWD passed an ordinance forbidding the use of groundwater within an area identified for Institutional Controls (ICs) as shown in Figure 4.

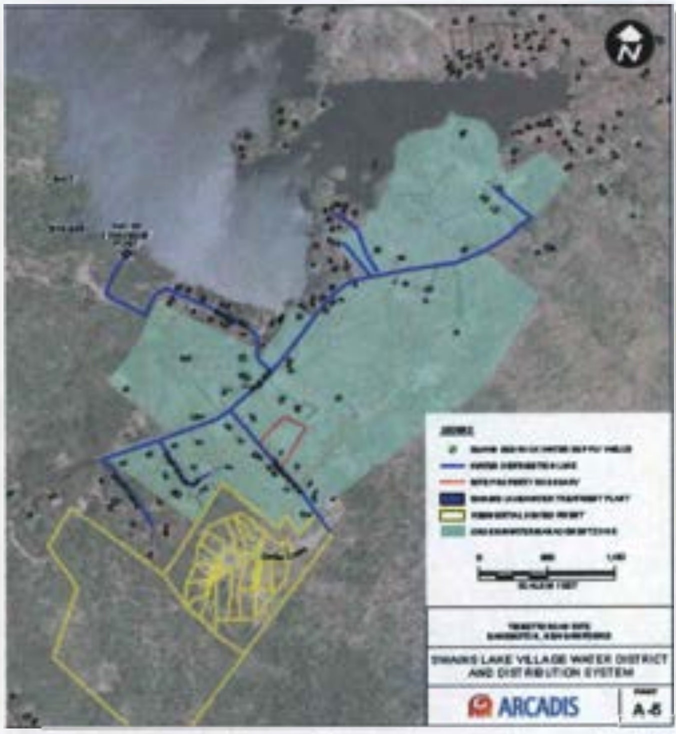


Figure 4: The light green area was the service area of the SLVWD from 1988 to 2014. Within this area no use of groundwater was permitted by an Ordinance passed by the SLVWD. The yellow lot lines in the southern portion of the figure are those of the Cedar Creek Subdivision that began construction in 2008. Contamination from the Site (ringed in red) reached drinking water wells in this subdivision by 2011. The PRP extended the water supply system and connected these homes in Fall 2015.

Swains Lake, designated as a class "B" waterbody by the State, was used for drinking water by the SLVWD from 1988 to 2012. The problems created by recreational use are described in the 2008 Five-Year Review and prompted the SLVWD to explore other water supply sources. The SLVWD Commissioners and the PRP agreed to investigate the potential to establish a bedrock

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[13] *Remedial Investigation, Vol. I*, p. 4-3 to 4-4.

[14] *Remedial Investigation, Volume II – Tables*, Table 4-15.

groundwater supply source on a property that abutted the drinking water treatment plant. Studies concluded that the bedrock wells were capable of supplying the SLVWD and were insulated from Site contamination. Two bedrock wells were installed in 2012 and the SLVWD is now supplied with drinking water from these wells exclusively.

Presently, the system supplies 3.5 million gallons of drinking water per year to 89 homes and a seasonal campground. The average daily demand is approximately 6,000 gallons per day for the residences and the balance of the usage is by the campground. The seasonal campground is approximately 3,000 feet north of the Site. The maximum daily demand is approximately 15,000 gallons. Figure 5 shows the location of the SLVWD water treatment plant, the wells that the water is extracted from, the extent of the current water distribution system, and the extent of the area restricted by the IC.

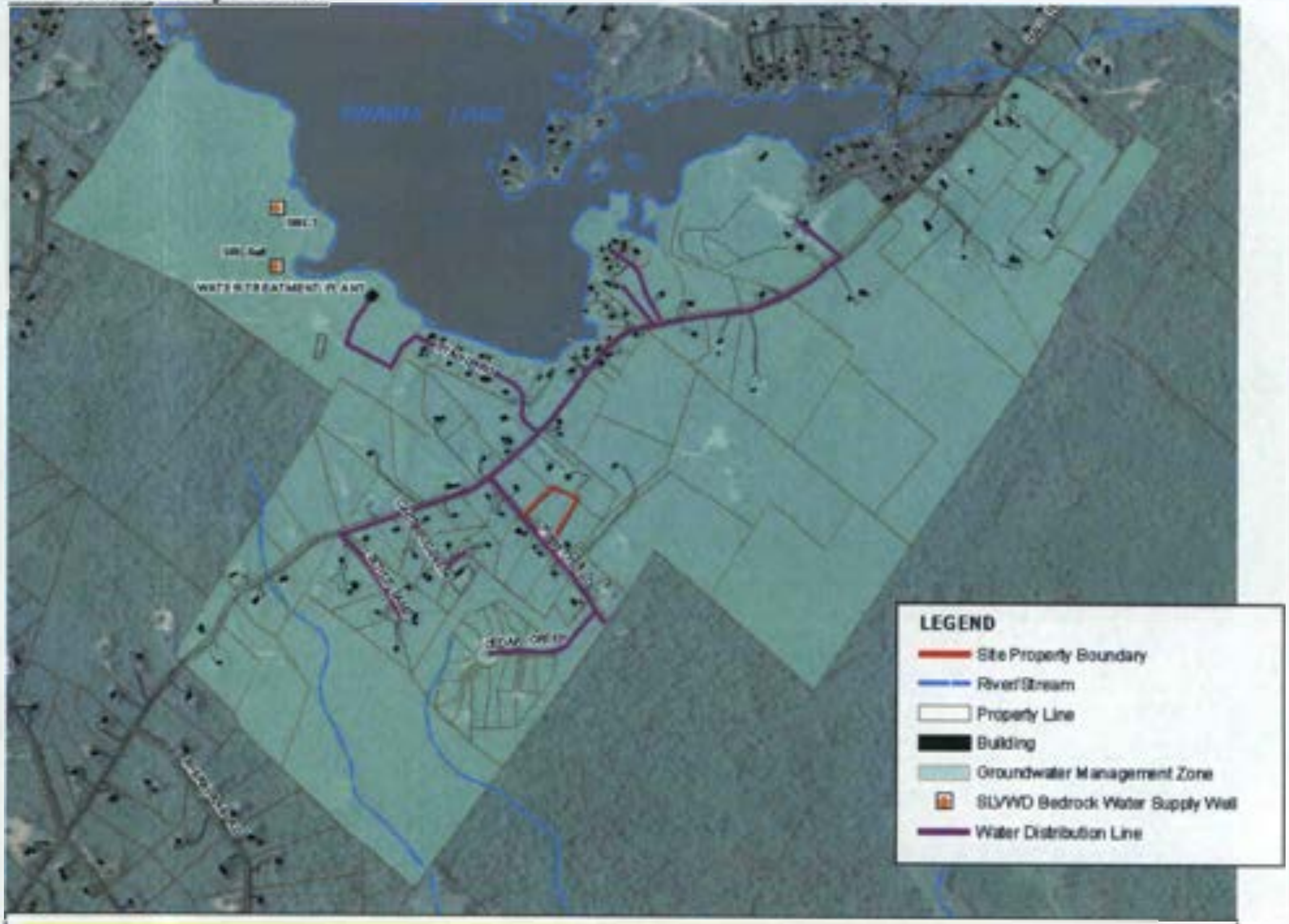

Figure 5: The present extent of the Swains Lake Village Water District service area and the Institutional Control that prevents groundwater use. The Cedar Creek area is now served and the wellhead area is protected. Hydraulic and contaminant monitoring is conducted to ensure that the supply wells are unaffected.

Summary Of Basis For Taking Action

The 1992 ROD documented the risk and established Interim Clean-up Levels (ICLs) for groundwater. These cleanup levels were proposed as "interim" to account for potential regulatory changes that may occur over the period of the remedy at the Site, in concentrations that are deemed to pose a risk. Prior to documenting the Site to be remediated to acceptable levels, EPA will evaluate the ICLs and determine if the concentrations present in the groundwater are protective of human health and the environment. If protective levels are met, the ICLs will become the Final Cleanup Levels. Table 1 lists the present ICLs, their basis, and what the maximum concentration was in the groundwater contaminant plume prior to remediation. No other exposure pathways to Site contaminants were found to generate an excess risk.[15]

Table 1: Groundwater Interim Cleanup Levels and Maximum Groundwater Concentrations prior to Remediation in 1996

Contaminant of Concern	Interim Cleanup Level (µg/l)	Basis of Interim Cleanup Level	Maximum Concentration in groundwater in 1996 (µg/l)[a]	
Inorganic compounds			**Overburden**	**Bedrock**
Arsenic	10[b]	MCL	446	80
Chromium	100	MCLG	353	221
Manganese	3,650[c]	Risk	44,500	11,400
Nickel	100	MCLG	252	80
Vanadium	256	Risk	290	90
Volatile Organic Compounds				
1,1,1 Trichloroethane	200	MCL	28	220
Trans-1,2 dichloroethene	100	MCLG	18,000	100
Cis-1,2 dichloroethene	70	MCLG	18,000	100
Bis(2-ethylhexyl)phthalate	4	MCL	8	240
Trichloroethene	5	MCL	27,000	3,000
Tetrachloroethene	5	MCL	3,200	11
Benzene	5	MCL	4,100	4,800
Toluene	1,000	MCL	140,000	9,000
Ethylbenzene	700	MCL	4,700	1,500
Xylene	10,000	MCLG	29,000	5,000
4-Methyl-2-pentanone	1,825	Risk	96,000	51,000
Naphthalene	1,460	Risk	440	145
Styrene	100	MCL	330	0

Notes:

[a] This represents the maximum concentration found at the Site during that time period.

[b] MCL of 10 became effective as of 22 February 2002 replacing the former value of 50 µg/L.

[c] Toxicity information for manganese and other contaminants of concern will be reviewed prior to any remedy completion and set at a protective level.

The details of the risk assessment, as set out in the 1992 ROD, follow:

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[15] *Remedial Investigation, Vol. I*, p. 7-8 – 7-9.

Table 16
INTERIM GROUND WATER CLEANUP LEVELS

Non-carcinogenic Contaminants of Concern (class)	Interim Cleanup Level (µg/l)	Basis	Target Endpoint of Toxicity	Hazard Quotient
1,2 Dichloroethene		MCLG	Blood	
(cis) (D)	70			0.19
(trans) (D)	100			0.14
Ethylbenzene (D)	700	MCL	Kidney & Liver	0.19
4-Methyl-2-Pentanone (D)	1,825	Risk	Kidney & Liver	1.00
Styrene (C)	100	MCL	Blood & Liver	0.014
Toluene (D)	1,000	MCLG	Kidney & Liver	0.14
1,1,1 Trichloroethane (D)	200	MCLG	Liver	0.06
Xylene (D)	10,000	MCLG	CNS-DBW	0.14
Naphthalene (D)	1,460	Risk	DBW	1.00
Chromium (D)	100	MCLG	No effect	0.55
Manganese (D)	3,650	Risk	CNS	1.00
Nickel (D)	100	MCLG	DBW	0.14
Vanadium (D)	256	Risk	No effect	1.00

HAZARD QUOTIENT SUMS TOXIC ENDPOINT	TOTAL
Blood	0.344
Kidney	1.33
Liver	1.404
Decreased Body Weight (DBW)	1.28
Central Nervous System (CNS)	1.14

TABLE 16, (cont.)
INTERIM GROUND WATER CLEANUP LEVELS

Carcinogenic Contaminants of Concern (class)	Interim Cleanup Level (µg/l)	Basis	Level of Risk
Benzene (A)	5	MCL	1.7×10^{-6}
Tetrachloroethylene (B_2)	5	MCL	3.1×10^{-6}
Trichloroethylene (B_2)	5	MCL	6.4×10^{-7}
Styrene (C)	100	MCL	3.5×10^{-5}
Bis(2-ethylhexyl)phthalate (B_2)	4	MCL	6.6×10^{-7}
Arsenic (A)	50	MCL	2.0×10^{-4}

Sum: 2.4×10^{-4}

Remedy Selection

After receiving and responding to comments from the public, the cleanup approach for the Site was finalized and documented in the September 29, 1992 ROD for this Site. The Remedial Action Objectives (RAOs) identified for the Site in the 1992 ROD included:

- Eliminate or minimize the threat posed to human health by preventing the ingestion of contaminated groundwater.
- Prevent further migration of groundwater contamination to uncontaminated portions of the overburden and bedrock aquifers.
- Restore contaminated groundwater in the overburden and bedrock aquifers to Federal and State applicable or relevant and appropriate requirements (ARARs), including drinking water standards, such that consumption of groundwater is protective of human health.
- Prevent the dermal contact, ingestion, or inhalation of contents of 12 drums of incinerator ash and three VOC-contaminated barrels used for water filtration.

To meet these RAOs, the 1992 ROD remedy included the following components:

- Upgrade and improve the existing drinking water distribution system.
- Dewater and treat, *in-situ*, contaminated aquifer matrix using a vacuum extraction system.
- Capture contaminated groundwater in the overburden and bedrock aquifers through the use of trenches and wells.
- Treat and remove inorganic and organic contaminants through flocculation and ultra-violet catalyzed oxidation.
- Discharge treated groundwater into the overburden and bedrock aquifers to enhance containment and recovery of contaminants.

Cleanup actions to protect public health began after EPA issued the 1992 ROD. In 1993, EPA extended a water line 3000 feet north along Hall Road to additional residences and a campground after contamination was found in those wells.

Under the 1995 CD, Ford agreed to, among other items, conduct the cleanup of the Site as specified in the ROD and to subsidize the SLVWD for a portion of its operating costs. Also under the 1995 CD, the SLVWD agreed to operate and maintain an alternate water supply for affected residences and to restrict the use of the groundwater in the impacted area through ICs.

To provide the ICs called for in the 1995 CD, the SLVWD enacted a local ordinance to prevent the use of groundwater at the Site as well as within the impacted area surrounding the Site. The enactment of the ordinance by the SLVWD also complied with the statutory requirements then identified under the State of New Hampshire's Groundwater Management Zone Regulations (Env-Ws 410) and present Env-Or 602.13.

Site Cleanup

In 1995, the PRP, through its contractor, Arcadis, began cleanup actions. Among the first actions was removing twelve drums stored at the Site that contained incinerator ash and three VOC-contaminated barrels used for water filtration. The 15 drums were transported off-site for disposal at a RCRA Subtitle C landfill in Model City, New York. The original, heavily fire-damaged, Johnson residence at the Site was demolished and the debris disposed of at a RCRA Subtitle D landfill in Rochester, New Hampshire.

The PRP began construction of the 1992 ROD groundwater remedy in the summer of 1995, a vacuum enhanced groundwater recovery (VER) system that removed and treated both soil vapor and groundwater from the overburden aquifer. The remedy was expanded and operated through 1997. The vacuum extraction wells were positioned within the overburden aquifer primarily in and around the three source areas, the drum storage areas A, B, and C at the Site identified in Figures 2 and 3. Area A is the western-most drum storage area, C is the northern-most, and B, the eastern-most. The Site was paved within the area of influence to reduce infiltration from the surface and enhance the effectiveness of the VER system as shown on photo 2.

Over its operational lifetime, the VER system removed and treated approximately 800 pounds of contaminants from the groundwater. During its peak operation, the VER system removed as much as 3.5 pounds of contaminants per day. Shortly before the system was shut down in 1997, the system was removing less than one ounce of contaminants per day.[16] The recovery of contaminants met the criteria in the 1995 CD to discontinue the VER. The recovery system was optimized to ensure that areas of high concentration in the overburden aquifer were addressed.[17] The VER system attained the ICLs for VOCs as identified in the 1992 ROD and Table 2 of this Five-Year Review beneath drum storage Area C.[18] In addition, VOC concentrations in the overburden aquifer beneath drum storage Area A were significantly reduced and were approaching cleanup levels at the time the VER system was shut down.[19]

Because the VER system had met the contaminant recovery standards set forth in the 1995 CD Scope of Work,[20] and the recovery efficiency of the VER system declined to less than one ounce per day, EPA considered other cleanup methods for the Site including pulsed hot-spot treatments using VER, bioremediation, and phytoremediation. After evaluating the alternatives, it was agreed by EPA, NHDES and the PRP to implement all three alternatives as the situation dictated.

Bioremediation was shown, through microcosm work of Dr. John Wilson of EPA's Ada laboratory, to be a significant contributor to contaminant reduction at the Site before remedial efforts began.[21] Bioremediation's importance was the initial consideration in selecting the phytoremediation remedy. In this instance, bioremediation required slower groundwater travel times to effectively degrade contaminants. The phytoremediation remedy was installed primarily to lower the water table and thus decrease infiltration and thereby slow the groundwater flow.

As a result, EPA issued an Amended Record of Decision on September 28, 1998 (the "1998 AROD") to change the overburden groundwater remedy to bioremediation and phytoremediation with limited hot spot remediation. Approximately 1,600 poplar trees (one-year old *Deltoides x Nigra* hybrid) were planted on the 1.9-acre site in May 1998 after the removal of the asphalt cap. The trees, which were three to five feet tall "whips" at the time of planting, were planted in rows ten feet apart and at intervals

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[16] **Note**: Although higher estimates were provided in subsequent documents, these figures were calculated at the time of the Construction Completion Report in 1998 and are believed to be the last, accurate estimates.

[17] *Findings of Subsurface Investigation, Tibbetts Road Site*, July 1997 (Geraghty & Miller, Inc (ARCADIS): Andover, MA).`

[18] *Tibbetts Road Superfund Site Amended Record of Decision*, September 28, 1998 (USEPA,RegionI,Boston) p. 12.

[19] *Amended Record of Decision*, p. 11.

[20] *Consent Decree*, Appendix B, Section VII. B., p. 39 – 46.

[21] *Amended Record of Decision*, p. 5, 6, and 10 – 14, and Appendix D.

of one tree every three feet. With the planting of the poplar trees, all construction activities associated with phytoremediation at the Site were complete, with only maintenance of the trees required. No additional activities were required to implement the bioremediation component of the 1998 AROD since it is a natural process which was already occurring at the Site. The Preliminary Close-Out Report was signed by EPA on September 29, 1998, signifying the completion of construction activities at the Site.

With respect to the bedrock groundwater pump-and-treat remedy in the 1992 ROD, during the design and construction of the overburden VER system, it became apparent that the removal of groundwater from the weathered bedrock aquifer would increase downward groundwater gradients. It was believed that this would increase the introduction of the more highly contaminated groundwater from the overburden aquifer and exacerbate the contamination in the weathered bedrock aquifer. Therefore, it was determined that recovery of bedrock contaminants would be coordinated to not interfere with the recovery of contamination in Area B. The 1998 AROD also amended the proposed pump-and-treat remedy in the weathered bedrock to include a bioremediation remedy that would be monitored to determine whether other *in situ* measures were necessary.[22]

In 2001, despite significant reductions in contaminants in the overburden groundwater at the Site, concentrations in the weathered bedrock remained very high. A submersible pump was installed at a bedrock monitoring well, 169R (the most highly contaminated area), and operated from August 21, 2002 to November 4, 2002. The extracted groundwater was treated and released to the overburden aquifer. Based on the results of pumping it was believed that an *in situ* chemical oxidizing agent (ISCO) may provide a better alternative to reduce concentrations.

An In Situ Chemical Oxidation (ISCO) pilot injection program began on November 2, 2003 with the injection of approximately 100 gallons of sodium permanganate solution into wells positioned in the weathered bedrock just north of the Site property line and drum storage area B. An additional injection of approximately 55 gallons of sodium permanganate was completed on December 30, 2003. The conclusion and recommendations of the initial pilot treatment was that the sodium permanganate was successful in reducing both chlorinated and non-chlorinated VOCs and that future applications may be useful, but will require longer reaction times.[23]

Arcadis performed a second phase of ISCO pilot injections in June and November of 2006. The 2006 application expanded on the 2003 injections by sealing the perimeter wells and injecting the oxidizer under pressure into wells screened across both the overburden and bedrock aquifers. A recirculation system extracted and re-injected groundwater to increase the hydraulic gradient as well as aid and control the distribution of the sodium permanganate. Although it was found that ISCO successfully reduced the concentrations of many of the target compounds, benzene was not reduced in concentration to a significant level and it was determined that additional applications of sodium permanganate would not be effective.[24]

In 2014, Arcadis began examining the effectiveness of Directed Groundwater Recirculation (DGR) in the area of contaminated bedrock groundwater. The intent was that using various geometries, pumping rates and frequencies, and amendments such as oxygen, that presently isolated and immobile

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[22] *Amended Record of Decision*, p. 28.

[23] *In-Situ Chemical Oxidation Pilot Test Interim Report and Supplemental Work Plan*, May 2005 (ARCADIS: Lowell, MA) p. 20 – 22.

[24] *In-Situ Chemical Oxidation Pilot Testing, Tibbetts Road Site…*, May6, 2008 (ARCADIS: Lowell, MA) p. 7 & 8.

contaminants in the bedrock could be recovered or treated in situ. That work continues with some promising results.[25]

Groundwater Contaminant Trends Since the 2013 Five-Year Review

The 1992 ROD estimated that it would take approximately twenty years (until 2005) to attain ICLs in both the overburden and bedrock aquifers.[26, 27] The 1998 Amended ROD estimated that bioremediation and phytoremediation would reach interim cleanup levels in 14 years (2012).[28] Cleanup levels were not attained in 2012 and, as of this FYR, overburden groundwater exceeds ICLs for metals and bedrock groundwater exceeds ICLs for both metals and VOCs. However, improvements have occurred in both overburden and bedrock groundwater since the 2013 FYR.

Overburden Groundwater

Subsequent hot spot treatment, biodegradation, and phytoremediation reduced contamination in the overburden such that only one well in the overburden aquifer, 57S, slightly exceeded the ICL for only one organic contaminant or VOC, trichloroethene (TCE), at 5.03 µg/L (ICL is 5 µg/L) during one sampling round in the past 5 years. The concentration of TCE in well 57S in 1985 was 23,000 µg/L, demonstrating the progress made since that time. All other Volatile Organic Compounds (VOCs) were below detection limits except for 155 µg/L of xylene also in 57S (ICL = 10,000 µg/L). It is further noted that the concentration of TCE in well 57S fluctuates with the amount of groundwater present such that a statistical test would find this well clean. Figure 6 shows that TCE, the only overburden organic contaminant that has exceeded the ICL (5 µg/L) since the 2013 FYR, has generally been below the ICL for TCE in 17 of the 18 sampling rounds since 2008.

Figure 6: Trichloroethylene (TCE) concentrations (µg/L) in Well 57S, 2008 to 2017

The only problem remaining in the overburden aquifer is the concentration of arsenic and manganese contaminants. Arsenic and manganese are pervasive overburden groundwater contaminants, but their concentrations over time have declined from pre-remedial conditions. Four overburden wells were

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[25] 2016 Annual Report, Tibbetts Road…, January 2017 (ARCADIS: Lowell, MA) Appendix E, p. 253.

[26] *Tibbetts Road Site Feasibility Study Report, Volume I: Text*, June 1992 (CDM Federal Programs Corporation, Boston, MA) p. 3-23.

[27] *Tibbetts Road Site Feasibility Study Report Appendices*, Appendix B, June 1992 (CDM Federal Programs Corporation, Boston, MA).

[28] *Amended Record of Decision*, p. 26.

sampled in 2016. Well MW-308 represents conditions in the southern portion of the Site where contamination has been historically lower. Well 57S is in the middle of the Site near the original source areas and the well with the highest historical concentrations for all contaminants. Wells 52S and 37D, are located just north of the Site and represent the higher and lower portions of the overburden aquifer, respectively, in the area of higher and more complex bedrock contamination. Table 2 provides a summary of the data pertinent to metal concentrations in the overburden aquifer.

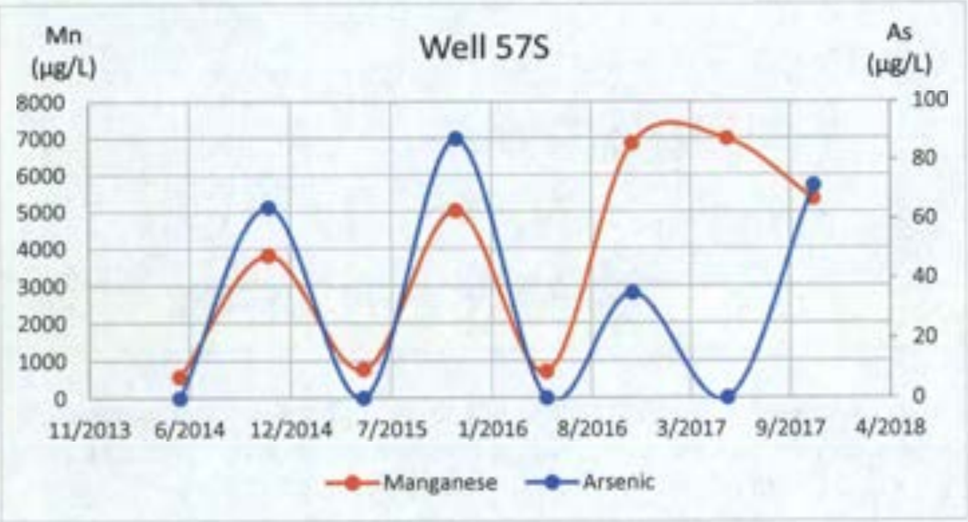
Table 2: Overburden Well Arsenic and Manganese Concentrations and Conditions in 2016

Well	2016	As (µg/L)	Mn (µg/L)	Fe[1] (total µg/L)	ORP	DO[2] (mg/l)
52S	May	<10	<15	<100	261.3	10.87
57S	May	<10	705	Not analyzed	96.62	0.92
	Nov.	35.1	6,840	9,490	28.5	1.77
37D	May	55.2	3,500	4,200	14.9	1.31
MW-308	May	15	8,940	Not analyzed	13.5	0.72
	Nov	9.9	9,770	34,500	29.6	1.05
ICL		10 µg/L	3650 µg/L			

[1] Total iron was measured to provide an indication of dissolved metal concentrations overall and a measure of redox chemistry much the same as the Oxidation-Reduction Potential (ORP).

[2] Dissolved Oxygen (DO) is used as a measure of microbial activity in the aquifer. Generally a DO of less than 1 mg/l indicates an anaerobic environment and the potential for increased dissolved metals, but much also relies on the substrate being reduced.

Examining the correlation of manganese and arsenic concentrations in Well 57S in the figure below shows a seasonal variation that could be interpreted as the concentration being driven by water levels or seasonal conditions or both. However, greater sampling frequency and the collection of atypical monitoring parameters may be more diagnostic of what drives this behavior.



Continued monitoring at the present frequency and with the present analytes is adequate for the following reasons: (i) increasing concentrations of dissolved oxygen (DO) in the overburden groundwater will reduce concentrations; (ii) concentrations are generally declining (the high concentration in the 2013 Five Year Review was 177 µg/L); (iii) no migration is occurring; and (iv) Institutional Controls are in-place and functional.

Bedrock Groundwater

Bedrock groundwater is more complicated than typical fracture flow in that glaciation 13,000 years ago created a highly fractured interval on the north side of the Site where the ice sheet, greater than 6,000 feet in thickness, grated against the hill's bedrock core. Three primary fracture sets govern bedrock groundwater flow and contaminant occurrence and fate:

1. Successive sub-horizontal fractures created by glacial loading that likely interbed with the lodgment till that was also created by the glacier.
2. Near surface, high angle fracturing transverse (strike northwest-southeast) to the glacial movement.
3. Deeper, high angle fractures that strike (trend) northeast-southwest that are the product of earlier tectonism during the rifting of North America from Europe and Africa approximately 180 million years before the present. It is also likely that a set of fractures orthogonal (northwest to southeast) to these fractures exist, albeit at a lower frequency than the near-surface fractures cited in the second bullet.

These conditions, plus that of how wastes discharged to the environment at the Site, resulted in a lens of contaminated groundwater at the northern edge of the Site within the bedrock aquifer on an adjacent property. That groundwater appears to be negligible except in the instances of sustained pumping such as that by the residents of the Cedar Creek subdivision discussed previously. The water supply wells for the SLVWD are isolated from Site groundwater by virtue of a large northeast-southwest trending fracture that runs along Hall Road and appears poorly connected with fractures to the northwest as demonstrated by pump tests as well as transducer testing and groundwater monitoring in Well 28R and other wells at the Site.[29]

Early investigations in bedrock at the Site included borehole radar, borehole geophysical logging, and sampling of wells surrounding the Site. Those investigations narrowed the area of interest to the northern half of the Site where most of the contamination exists due to the shallow, highly fractured environment in the shallow (0 to 60 feet) and intermediate depths (60 to 165 feet). Currently, in the northern portion of the Site, monitoring is performed in multi-level monitoring wells to develop a conceptual site model of contaminant flow. Figure 7 shows bedrock and overburden monitoring wells and injection and extraction wells for the ISCO (IW and EW wells).

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[29] 2016 Annual Report, Arcadis.

Figure 7: Wells relevant to the contamination in bedrock at the Site. North is at the top of the figure, and the Site property boundary is shown in red. Tibbetts Road may be seen in the lower left corner. This includes overburden wells as lime-colored triangles, bedrock wells as red triangles and wells used for the Directed Groundwater Pilot as solid green circles with a dot in the middle. This figure is an excerpt from Figure 2 of the 2016 Annual Report, Arcadis.

The organic contaminants TCE, 1,2-DCE and Benzene are the predominant contaminants at the Site and are diagnostic of the conditions in the bedrock groundwater. These contaminants are also the only ones that currently exceed ICLs although detections of ethylbenzene, toluene and xylene occurred. The maximum concentrations of these three compounds were not even a fraction of their ICL.[30] The concentrations in bedrock at three depths in November 2016 are summarized in Table 3, below:

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[30] 2016 Annual Report, Table 4, Arcadis.

Table 3: Frequency and Highest Concentrations for Benzene, Trichloroethylene, and 1,2-Dichloroethylene in Bedrock Groundwater Monitoring Wells, November 2016.

Contaminant (ICL)	**Depth** (feet)	**Frequency** (# Exceeds ICL / # of wells sampled)	**Highest Concentration** (Concentration (µg/L) – Well ID)
Benzene (5)	0 to 60	5/16	152 – 203R, but the next highest is 21.6 – MW301.
	60 to 165	4/17	46.2 – IW101.
	165 to 300	2/6	7.6 – MW301.
Trichloroethylene (5)	0 to 60	0/16	0.9 – 205R.
	60 to 165	2/17	97.7 – 67R & 11.3 – 63R.
	165 to 300	1/6	10.5 – 61R.
1,2-Dichloroethylene (70)	0 to 60	1/16	142 – 203R.
	60 to 165	3/17	77 – IW102.
	165 to 300	1/6	190 – 65R.

Figure 7, above, depicts the locations of all the wells in this table.

Examining Table 3, it is evident that organic contaminants are not pervasive across the Site, but limited to only small areas within the bedrock. Generally, the few exceedances are north of the Site or on the northern half of the Site. The 2016 Annual Report shows these concentrations individually and attempts to draw plumes. However, the "plumes" shown in that document are more similar to probability plots than an indication of overall concentrations, as the flow and presence of contaminants in fractured bedrock is generally limited by fracture frequency and aperture.

Concentrations of these contaminants are, with few exceptions, relatively low and compared to historic data, greatly reduced. Benzene, at the 0 to 60 foot level, has a very high concentration, but the four remaining wells are at 21 µg/L or less. Similar behavior is seen for TCE at 60 to 165 feet. 1,2-DCE is a daughter product in the microbial degradation of TCE and thus it would be expected that these concentrations would be significant, but they are not overwhelming in frequency or concentration. This may be indicative of a withering source of contamination.

The PRP has voluntarily conducted DGR studies in bedrock in an effort to accelerate the restoration of groundwater and eliminate the costs associated with monitoring and reporting, Site maintenance, and its 75% cost-share for operation of the SLVWD. However, the persistence of arsenic and manganese contamination in bedrock may hinder this effort. Similar to overburden groundwater, it is believed that the redox environment of the groundwater liberates arsenic and manganese from the native aquifer materials. Table 4, below, excerpted from Table 7 of the 2016 Annual Report, summarizes the occurrence of arsenic and manganese in bedrock groundwater.

Table 4: Comparison of Summary Statistics for Arsenic and Manganese in Bedrock Groundwater, 2016.

Year		High Concentration (µg/L)	Mean Concentration (µg/L) – Frequency (# detections / # wells sampled)
1996	As	960	84 – 12/18
	Mn	11,400	5280 – 1/18
2008	As	160	43 – 17/18
	Mn	490,000	36,913 – 8/28
2013	As	96	23 – 42/48
	Mn	42,000	1,624 – 46/48
2016	As	820	39 – 32/52
	Mn	5,580	984 – 49/52

This table is excerpted from Table 7 of the 2016 Annual Report produced by Arcadis.

Table 4 chooses 4 particular years to focus on:

- 1996, as these concentrations are prior to any groundwater remedial action and after the soil removal actions.
- 2008, the second Five-Year Review and 10 years after completion of the vacuum extraction remedy and implementation of the bioremediation and phytoremediation remedy.
- 2013, the last Five-Year Review.
- 2016, the last sampling year before this analysis.

The concentration of manganese in 2008 is the result of potassium permanganate being injected to reduce concentrations of VOCs as part of a pilot study by the PRPs. The mean value is driven by that singular high concentration and a better measure of the distribution around the mean should have been considered, but it is evident by examining the bulk of the data that the actual mean, outside of the treatment area, is much lower. This is evident as the monitoring rounds subsequent to 2013 show concentrations of manganese consistent with overburden groundwater that was not treated with potassium permanganate.

Overall, arsenic and manganese concentrations remain well above the ICLs in bedrock groundwater and are pervasive. Continued monitoring and a focus on controlling parameters, similar to that for the overburden concentrations of arsenic and manganese may be needed.

Summary

The groundwater remedy is functioning as depicted in the 1998 AROD; however, metal contaminants arsenic and manganese were not accounted for in that document and will be the limiting contaminants. VOCs such as TCE and 1,2-DCE, as well as organic contaminants such as benzene will persist in bedrock. The pilot remedies such as DGR may be successful in hastening the decline of VOCs and organic contaminants and should continue. Monitoring can be maintained as it has been, but additional analytes, monitoring methods and frequencies should be considered to develop better cleanup times.