Proceedings of the Annual International Conference on Soils, Sediments, Water and Energy

Volume 13 Article 10

1-18-2010

Fisherville Mill – A Case Study – Cost Effective Remediation Through Collaboration

Paul Ollila
MassDEP

Jim Soukup
Weston Solutions, Inc.

Bette Nowack
Stone Environmental, Inc.

Eugene Bernat
Fisherville Redevelopment Corporation

Dean Brammer
Weston Solutions, Inc.

See next page for additional authors

Authors
Paul Ollila, Jim Soukup, Bette Nowack, Eugene Bernat, Dean Brammer, Eric Hultstrom, and Janis Tsang

Chapter 9

FISHERVILLE MILL - A CASE STUDY- COST EFFECTIVE REMEDIATION THROUGH COLLABORATION

Paul Ollila[1§], Jim Soukup[2], Dean Brammer[2], Bette Nowack[3], Eugene Berat[4], Eric Hultstrom[5], Janis Tsang[6]

[1]MassDEP, 627 Main Street, Worcester, MA 01608 [2]Weston Solutions, Inc., 1 Wall Street, Manchester, NH 03101, [3]Stone Environmental, Inc., 18 North Main Street, Concord, NH 03301, [4]Fisherville Redevelopment Corporation, 95 State Street, Suite 812, Springfield, MA 01103 [5]Woodard & Curran, Inc., 980 Washington Street, Dedham, MA 02026, [6]USEPA, Region I, One Congress Street, Suite 1100, Boston, MA 02114

ABSTRACT

The Fisherville Mill site is located on the Blackstone River in Grafton, MA. Soil and groundwater are contaminated with chlorinated VOCs and petroleum. The mill and a groundwater recovery system designed to prevent VOCs from migrating to a public water supply well (Well # 3) located approximately 1000 feet southwest of the site were destroyed by fire in August 1999. In November 2000, TCE was detected in Well #3. After notification, site investigation efforts focused on evaluating potential migration pathways to Well #3.

Based on site investigation results, the USEPA installed a temporary dam to alter groundwater flow directions and reduce risk to Well # 3. In Situ Chemical Oxidation (ISCO) using sodium permanganate was selected to decrease TCE concentrations in the source area and provide long-term protection for Well # 3.

Fisherville Redevelopment Company (FRC) took ownership of the site in 2004. A collaborative approach and strategy was developed between FRC, MassDEP and the Town of Grafton that would encourage significant remedial actions while environmental assessment and engineering activities were ongoing. Work completed includes installation of a # 6 oil interception and collection infrastructure, and encapsulation of asbestos impacted debris and lead contaminated soil in flowable fill.

Keywords: Fisherville, Grafton, trichloroethene, permanganate, flowable fill, Brownfields

§ Corresponding Author: Paul Ollila, MassDEP, 627 Main Street, Worcester, MA 01608, E-mail: Paul.Ollila@state.ma.us

1. INTRODUCTION

The Fisherville Mill Site is located between the Blackstone River and Blackstone Canal in the southern part of Grafton, Massachusetts (Figure 1). The original mill produced textiles from 1831 to the late 1870s, was destroyed by fire, and replaced by a much larger mill that produced cotton goods until 1949. From 1949 to 1986, the mill was used for manufacture of tool and die parts, machine tool stamps, lawn furniture, and foam rubber and fabrics for car seats. The mill was destroyed by fire in 1999 shortly after ownership passed from the Town of Grafton to the

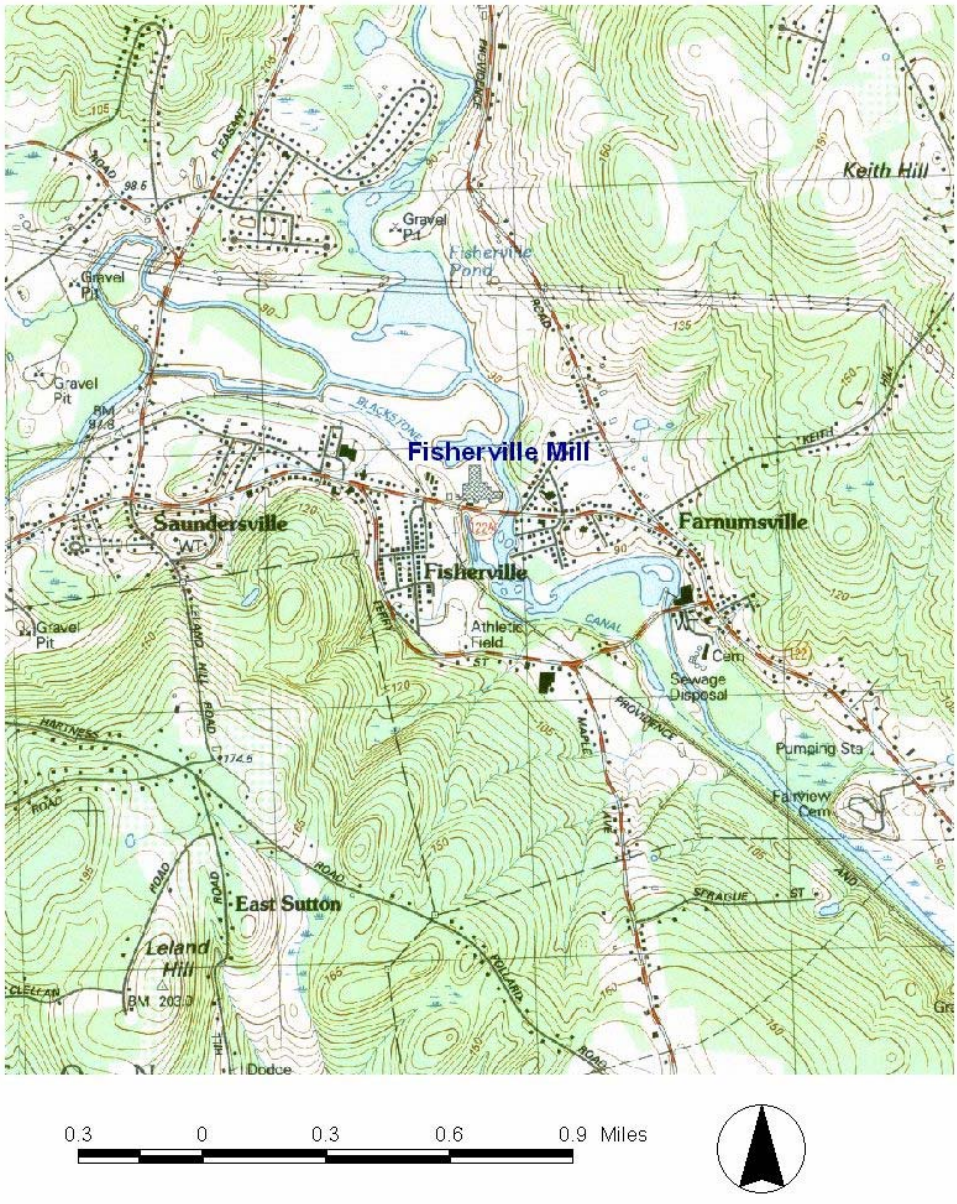

Figure 1. Site location map. Base map is a portion of the USGS 7.5 x 15' Milford, MA quadrangle.

Central Massachusetts Economic Development Authority (CMEDA). Main Street (Route 122A) divides the site into two roughly equal areas (Figure 2). The mill occupied the area north of Main Street. The area south of Main Street (the "peninsula") is undeveloped and is bounded by the Blackstone River on the east and the Blackstone Canal on the west and south.

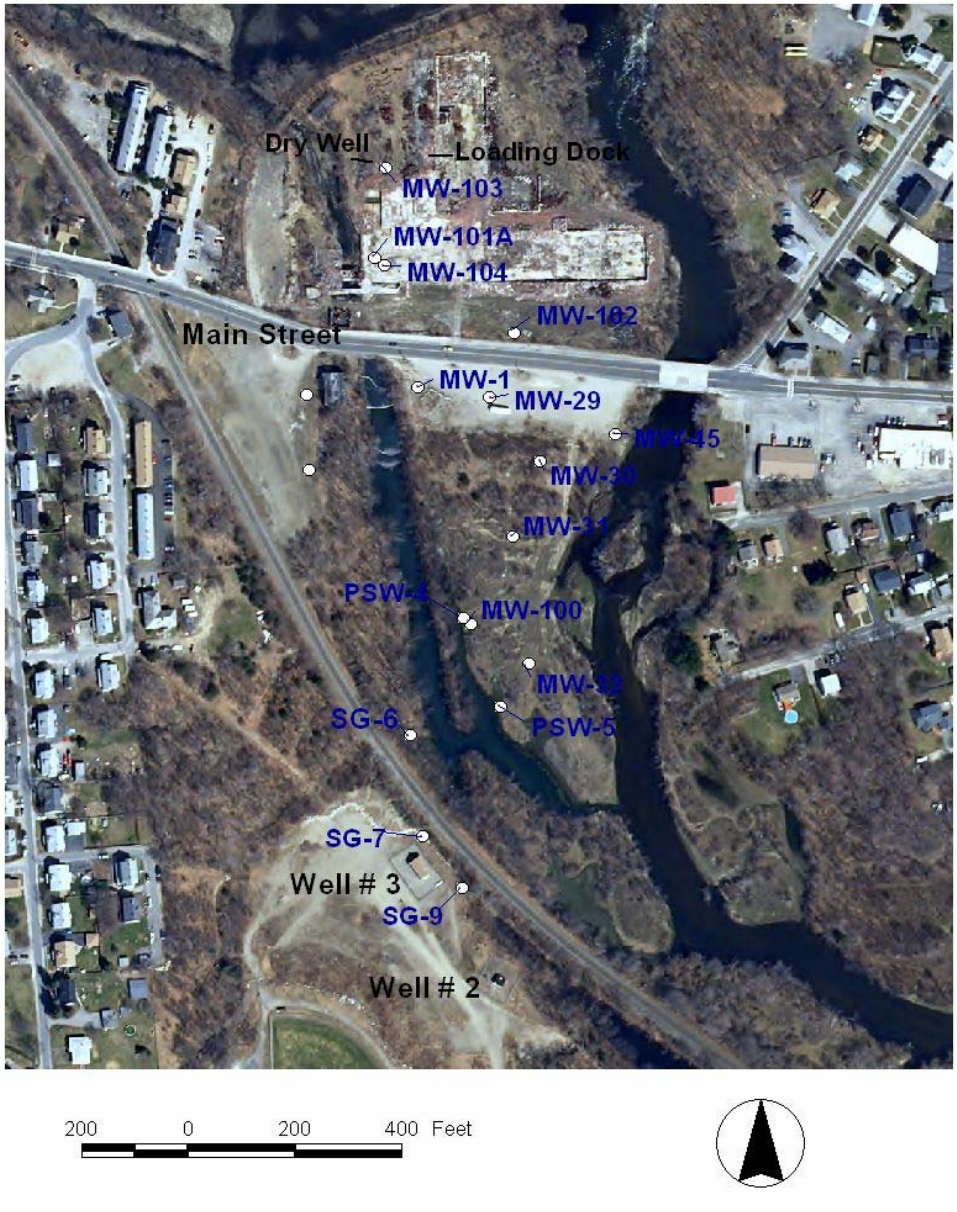

Figure 2. Orthophoto showing the former mill, the peninsula and monitoring well locations.

Major environmental problems include No. 6 oil in soils, sediment and surface water, and chlorinated volatile organic compounds (CVOCs) in soil and groundwater. The mill owners began capturing oil in the canal in the early 1970's and removed two 20,000-gallon underground storage tanks in 1987. Oil-saturated soils in the subsurface are a continuing source of oil in the

canal. CVOCs were first reported in 1986 and threatened a public water supply well located approximately 1200 feet south (Well # 2) of the Site. MassDEP installed a groundwater recovery system in 1996, at the same time that the South Grafton Water District (SGWD) installed a second water supply well (Well # 3) approximately 1000 feet south of the site. The SGWD only used Well # 3 in the late summer and fall after the fire destroyed the groundwater recovery system. MassDEP requested assistance from the EPA after receiving notification from the SGWD that TCE had been detected in a sample collected from Well #3 in November 2000, 15 months after the fire.

Work conducted prior to the 1999 fire is summarized in Handex (1997) and included deployment of absorbent booms in the Blackstone Canal, excavation of petroleum contaminated soils, removal of two 20,000-gallon underground storage tanks, and installation of a groundwater recovery system. MassDEP maintained absorbent booms in the canal from 1990 to 2004, conducted numerous site investigations to evaluate the extent of oil and CVOC contamination, and operated the groundwater recovery system between 1996 and 1999. The U.S. Environmental Protection Agency, Region 1, Emergency Planning and Response Branch (EPA), CMEDA, and MassDEP cleaned up most of the asbestos-contaminated debris after the fire and the EPA removed lead-contaminated ash from the former building foundation. However, the fire at the mill had significantly complicated cleanup efforts, primarily with respect to two aspects of site cleanup. The fire dispersed asbestos fibers throughout the property commingling asbestos with other debris and destruction of the MassDEP groundwater recovery system allowed CVOCs to migrate from the source area toward the SGWD wells.

The EPA Superfund Innovative Technology Evaluation (SITE) program and CMEDA conducted a pilot project for enhanced bioremediation of CVOCs from 2000 to 2002. After trichloroethene was detected in SGWD Well #3 in November 2000, the EPA, SGWD, and MassDEP evaluated potential migration pathways between the site and the SGWD well. Based on these investigations, the EPA installed a temporary dam between the Blackstone Canal and Blackstone River in 2002, and began chemically oxidizing CVOCs under the former mill in June 2003.

Fisherville Redevelopment Corporation (FRC) took ownership of the site in 2004 and is preparing the site for redevelopment while continuing the cleanup. To date, FRC has encapsulated asbestos contaminated soils with flowable fill, installed an oil recovery system and begun installation of a soil vapor extraction system designed to address shallow CVOC contamination. FRC efforts also involved public relations, community outreach, and public planning for this project.

The first part of this paper describes site investigation efforts after the 1999 fire. The second part describes risk reduction measures implemented to minimize risk to SGWD Well #3. The third part discusses cleanup and redevelopment issues after FRC took ownership of the site.

2. SITE INVESTIGATION

2.1 Methods

Site investigation activities conducted after the 1999 fire include advancement of borings and installation of monitoring wells using hollow stem augur, drive and wash, and direct push techniques. Borings for bedrock monitoring wells were advanced with an air hammer and wells were completed as standard two-inch monitoring wells. Direct push techniques were used to collect groundwater samples at five-foot vertical intervals in the former mill and on the western side of the peninsula. Piezometers installed in the Blackstone River and Canal consisted of 1.25-inch diameter clear plastic tubes installed such that the bottom end of the tube was 1-2 feet below the sediment surface and the upper end was above the water surface.

Soil samples were collected using split-spoon samplers or direct-push techniques. Soils were screened in the field for VOCs using the jar-headspace method. Soil samples collected for VOC analysis were preserved in methanol and analyzed using EPA Region I's Standard Operating Procedure for Head Space Screening for Volatile Organic Compounds (USEPA, 1998) and/or EPA Method 8260b.

Groundwater samples were collected with bailers, submersible centrifugal and bladder pumps, peristaltic pumps, and inertial pumps. Polyethylene diffusion bag samplers (ITRC, 2004) were deployed in selected monitoring wells. Peristaltic and inertial pumps primarily were used during vertical profiling. Results for samples collected using conventional three-volume purge and low-flow (EPA, 1996) techniques were similar and sampling method did not appear to cause bias in long-term monitoring results. Results from polyethylene diffusion bag samplers agreed with pumped sample results in some cases. In other cases, particularly in a bedrock monitoring well, vertical concentration gradients made placement of the sampler critical to achieving good agreement between sampling methods. Groundwater and surface water samples were analyzed for VOCS in mobile laboratories using headspace techniques (Pine & Swallow, 2000a; USEPA, 1998) and/or in fixed laboratories via EPA Method 624 or 8260b.

Passive vapor diffusion samplers (PVDS) were constructed and deployed following methods described by Church et al. (2002). Air samples from the VOA vials were analyzed in the field with a portable gas chromatograph (Pine & Swallow, 2000b).

Pumping tests were conducted by pumping SGWD Well #3 at a rate of 450 gallons per minute. Eight pressure transducer data loggers (In-Situ Troll or Mini-Troll) were installed and collected water level/pressure and temperature measurements every 15 minutes for ten days prior to an initial 4-hour pumping test. Ten additional data loggers were installed one month prior to 4 hour per day and 8 hour per day, 5-day pumping tests. Data was collected at 2-minute intervals during the 5-day pumping tests.

2.2 Hydrogeology

Fill and alluvial deposits overlie a discontinuous peat layer, approximately 30-60 feet of stratified sand and gravel, and 0-17 feet of dense sand, silt and cobbles (till) over bedrock (Figure 3). Hydraulic conductivity estimates for the sand and gravel aquifer near the SGWD wells exceed 400 ft/day. Till overlies bedrock on hills located on either side of the Blackstone River Valley and granitic gneiss is exposed on the east bank of the Blackstone River near the Fisherville Dam. Based on boring and seismic refraction data, the center of a bedrock depression is located under the peninsula (HMM, 1993). Depth to bedrock exceeds 60 feet in this area. Fill materials consist of sand and gravel, peat, and minor amounts of brick and other debris. Fill may be as much as 25 feet thick near the Blackstone Canal in the former mill area.

Prior to 1995, groundwater elevations and gradients were strongly influenced by dams located north (Fisherville Dam) and south (Farnumsville Dam) of the site. The Farnumsville Dam was used to generate electricity and releases from the dam caused an approximate 2-foot daily change in surface and groundwater levels on the peninsula. The USGS (1995) documented that fluctuations in groundwater levels were similar to fluctuations in stream stage (Figure 4). The Farnumsville Dam has not been used to generate power since 1995 and has deteriorated over

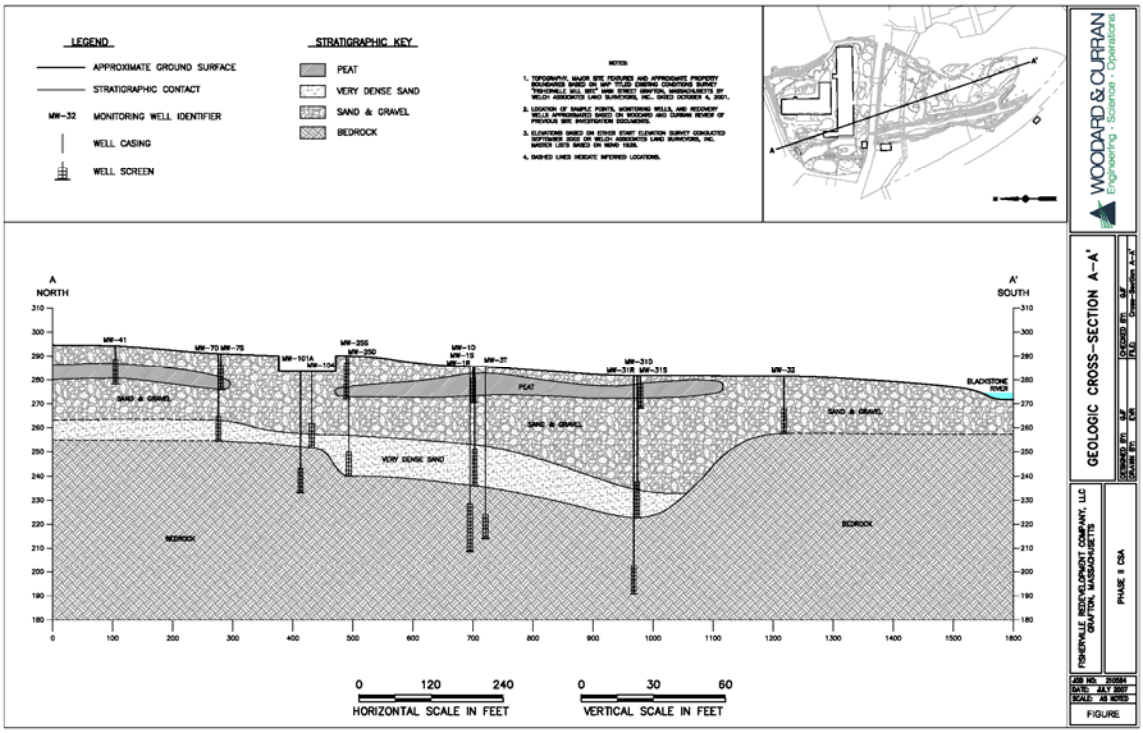

Figure 3. Geologic cross section from Fisherville Pond to the southern end of the peninsula.

time. Average water levels behind the dam decreased by about 2 feet between 1994 and 1996 and average horizontal groundwater gradients under the peninsula are probably slightly steeper than in the past because of the deterioration of the Farnumsville Dam and intermittent pumping of SGWD Well #3.

The Fisherville Dam created the impoundment (Fisherville Pond) that fed the mill canal. In 1995 the dam's spillway gates were welded open and water only flowed through the mill canal during wetter parts of the year. However, debris jams intermittently have restricted flow in the spillway and increased water flow through the canal. Water generally was not present in the mill canal during the summer and fall from 2000 until 2005. During 2006 and 2007 water has been present in the mill part of the canal during most of the summer. South of Main Street (Figure 2), groundwater discharge maintains flow in the canal except under very dry conditions in the late summer and fall. Water elevations in the canal strongly influence groundwater flow directions under the peninsula.

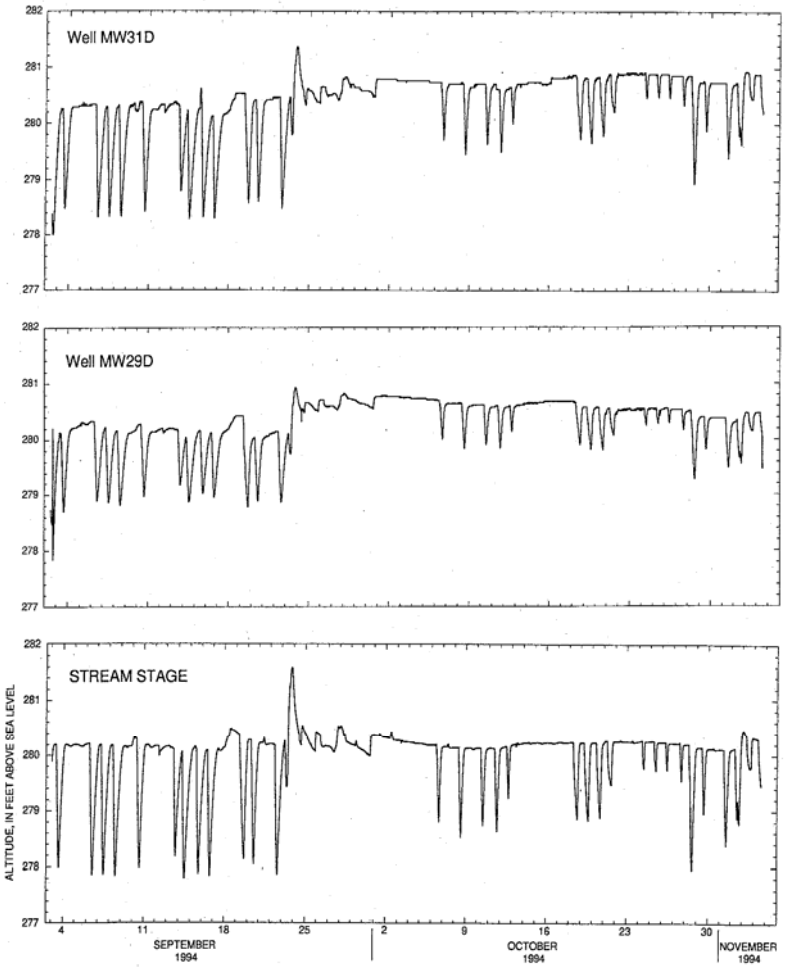

Figure 4. Groundwater and surface water elevations measured in 1994 by the USGS (Desimone and Barlow, 1995).

In order to evaluate potential migration pathways to Well #3, the EPA (Weston, 2002) installed ten overburden and three bedrock monitoring wells, and installed eighteen pressure transducer data loggers in new and existing monitoring wells and surface water gauges. Three overburden (SG-7S, SG-9S, SG-9D) and two bedrock wells (SG-7R, SG-9R) were installed near SGWD Well #3, three overburden wells (MW-100S,M,D) were installed near PSW-4, and three overburden wells (MW-102, 103, and 104) and one bedrock well (MW-101A) were installed in or near the former mill (Figure 2). These wells supplemented an existing network of monitoring wells.

Figure 5 is a potentiometric contour map based on July 2001 gauging data for deep overburden monitoring wells. On July 16, 2001, deep groundwater was flowing under the canal towards the Blackstone River. Based on gauging data from monitoring wells near the canal, and piezometers and surface water gauges installed in the canal, shallow to intermediate depth groundwater was discharging to the canal. This is not the case during dry parts of the year when Well #3 is in use.

Figure 5. Potentiometric contours (277.6 and 277.4 feet) based on water elevations measured in deep overburden monitoring wells on July 16, 2001.

Water levels in piezometers installed in the Blackstone River and Canal in the summer and fall of 2000 indicated that the Blackstone River was neutral or losing near Main Street and became a gaining stream as it dropped in elevation south of Main Street. The canal was gaining except when SGWD Well #3 was pumping. Upward gradients decreased and eventually reversed under parts of the canal when Well #3 was in use.

Monitoring well gauging data also indicated relatively steep downward gradients in the former mill area. Recent investigation in the mill area identified perched water under the former mill and apparent downward gradients may be artifacts of subsurface structures and the nature of the fill material.

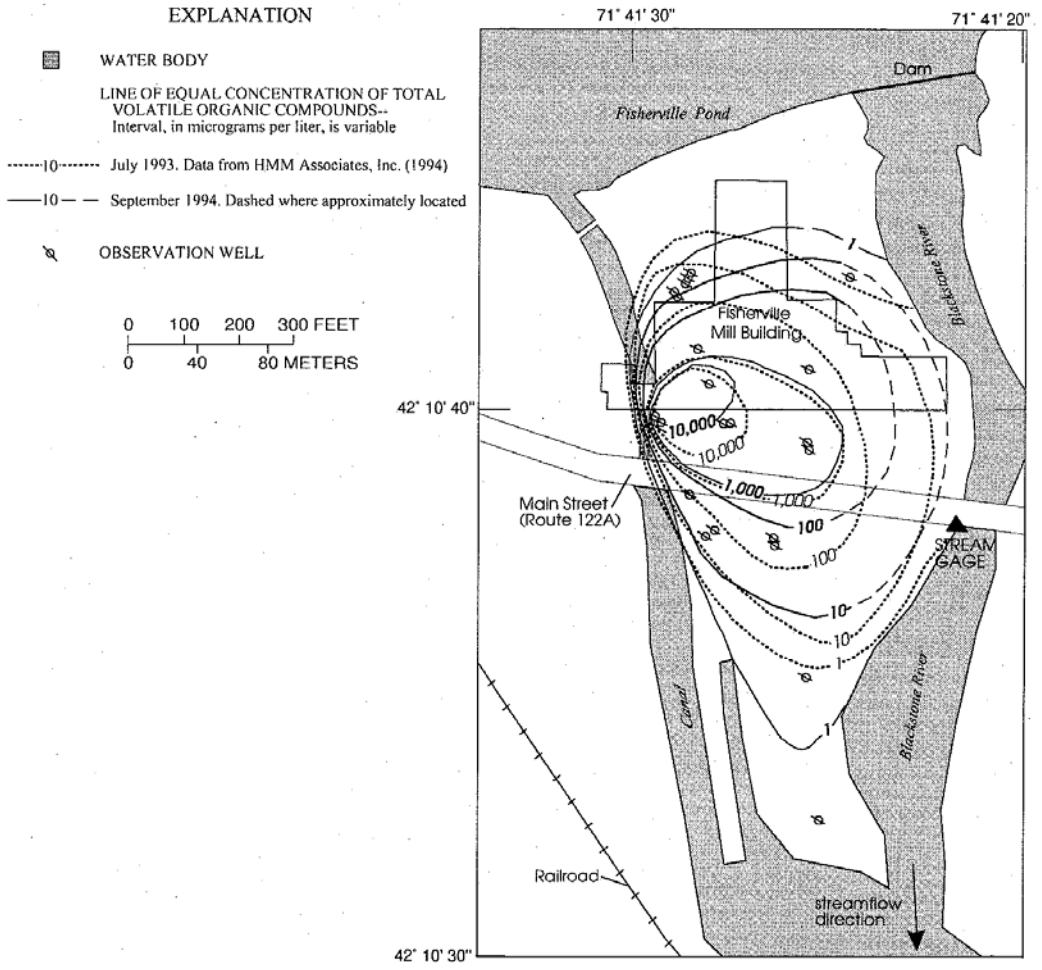

Figure 6. Total VOCs (ug/l) measured in groundwater samples collected in July 1993 (HMM, 1994) and in September 1994 (Desimone and Barlow, 1995).

2.2.1 Contaminant Distribution

Probably the best indicator of the change of hydrologic conditions between 1994 and 2000 is the change in contaminant distribution patterns. Figure 6 shows total VOC concentrations in 1993 and 1994. VOCs were either not detected or at very low concentrations in wells located on the southern part of the peninsula. Figure 7 shows the changes in TCE concentrations in selected peninsula monitoring wells after the fire. TCE is the principal VOC in all the selected wells. After the fire, TCE concentrations first increased in MW-1D followed by MW-31R, MW-1R, MW-31D, MW-31S, and MW-32D. In the fall of 2000, VOC concentrations in peninsula monitoring wells were higher and VOC contamination extended further south than in 1993 and 1994.

MassDEP conducted a passive vapor diffusion sampler (PVDS) study in June 2000 in order to provide more information about the fate of the VOC plume on the peninsula (Figure 8). TCE contaminated water was discharging to the Blackstone River and Canal but VOCs were not detected in samplers located near the southern end of the peninsula. CVOC concentrations in surface water samples collected from the canal near the former mill have been as high as 574 ug/l. CVOCs have not been detected in surface water samples collected from the Blackstone River.

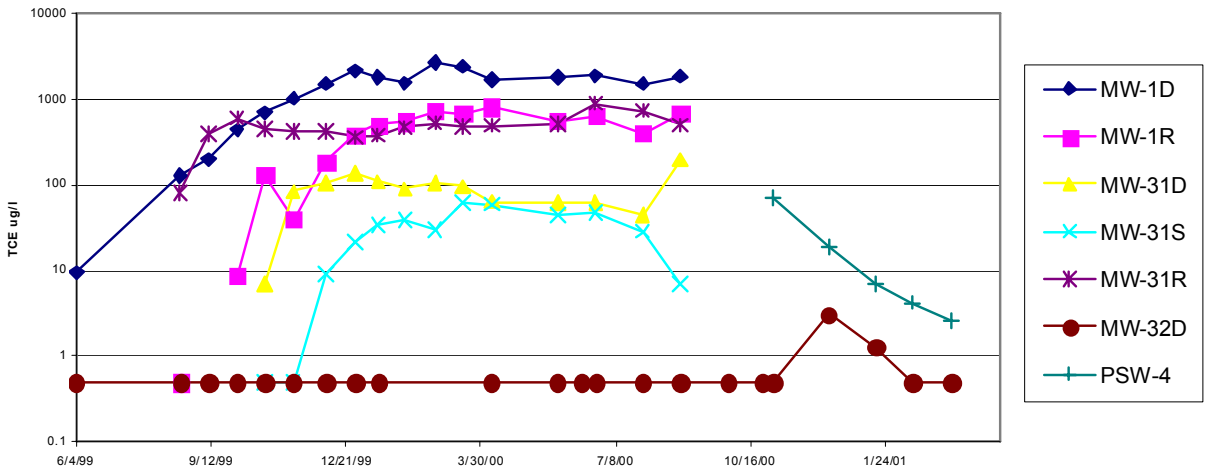

Figure 7. VOC concentrations measured in groundwater samples after the August 1999 fire.

Figure 8. TCE concentrations measured in passive vapor diffusion samplers (ppbv) in June 2000.

MassDEP (Pine & Swallow, 2000) advanced 17 one-inch microwells at the site in October 2000 in order to further evaluate groundwater contamination in the presumed source area and to evaluate the vertical distribution of VOCs under the peninsula near the locations where the PVDS indicated contaminated groundwater was discharging to the canal. The presumed sources of contamination at the site are a dry well located north of the former boiler room and a loading dock area to the east of the former drywell (Figure 2). Shallow groundwater samples collected during vertical profiling near the dry well contained high concentrations of cis-1,2-dichlorothene and relatively low concentrations of TCE. High TCE concentrations (>1000 ug/l) were limited to the deep aquifer in an area south of the former dry well and loading dock and under the western end of the former mill with the highest concentrations (>50,000 ug/l) limited to the area near the western end of the former mill.

Figure 9 shows TCE concentrations measured in groundwater samples collected at five-foot vertical increments on the western side of the peninsula near (PSW-4) and south (PSW-5) of the MW-100 location. CVOCs were present in the upper part of the aquifer, CVOCs were not present at intermediate depths, and concentrations were highest near the bottom of the overburden aquifer.

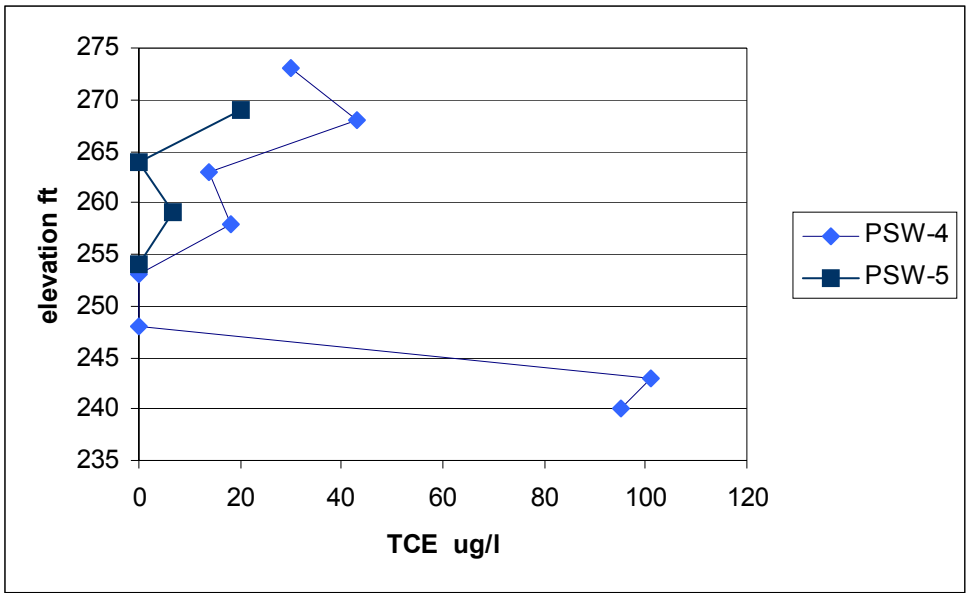

Figure 9. TCE measured in groundwater samples collected at five-foot intervals on the western side of the peninsula at locations PSW-4 (near MW-100) and PSW-5.

SGWD Well #3 is screened at the base of the sand and gravel aquifer from 37 to 43 feet below grade and has a maximum permitted yield of 450 gallons per minute. In January 2001, the SGWD reported that 0.7 ug/l of TCE had been detected in a sample collected from Well #3 in November 2000. The SGWD stopped using Well #3 shortly after the November sample was collected because water levels had recovered at a well (Well #1) located in another part of the town. Interpretation of the November sampling results for Well #3 was difficult because TCE was not detected in a sample collected from monitoring well SG-7 that is located between Well #3 and the Fisherville Mill Site. After the SGWD stopped using Well #3 and after water levels increased, TCE concentrations in PSW-4 decreased compared to concentrations measured in November 2000 (Figure 7).

2.2.2 Pumping Tests

The SGWD, EPA and MassDEP jointly conducted pumping tests in July 2001. The SGWD pumped Well #3 at a rate of 450 gallons per minute for 4 hours per day from July 16 to July 20, 2001, and 8 hours per day from July 23 to July 27, 2001. Figures 10 and 11 show water levels in monitoring wells on the west and east sides of the canal respectively. Pumping had little, if any,

effect on water levels on the eastern side of the canal (Figure 11). Daily oscillations in water levels in wells located on the eastern side of the canal and in MW-9R, a bedrock well located on the western side of the canal, are related to water level changes in the Blackstone River. Drawdown during the eight hour pumping test briefly created an upward vertical gradient from bedrock into the overburden aquifer near Well #3, but did not induce infiltration of surface water near SG-6 (Figures 2 and 10). However, extrapolation of trends observed during the pumping tests indicated that continued pumping would induce surface water infiltration near SG-6.

In October 2001, the SGWD began using Well #3 because of low water levels at Well #1. Well #3 operated for approximately 10 hours each day from October 23 to October 25. A total of 792,000 gallons of water was pumped over the three days. The SGWD gauged wells at the beginning and end of pumping on each day. Figure 12 is based on water elevations measured prior to the pumping test conducted in July 2001. Figure 13 is based on water elevation data collected at the end of pumping on October 25. Sampling results and water level measurements from October 25, 2001 are consistent with deep flow under the canal. TCE was detected in SG-6 but was not detected in DP-4A despite downward gradients between the canal and DP-4A.

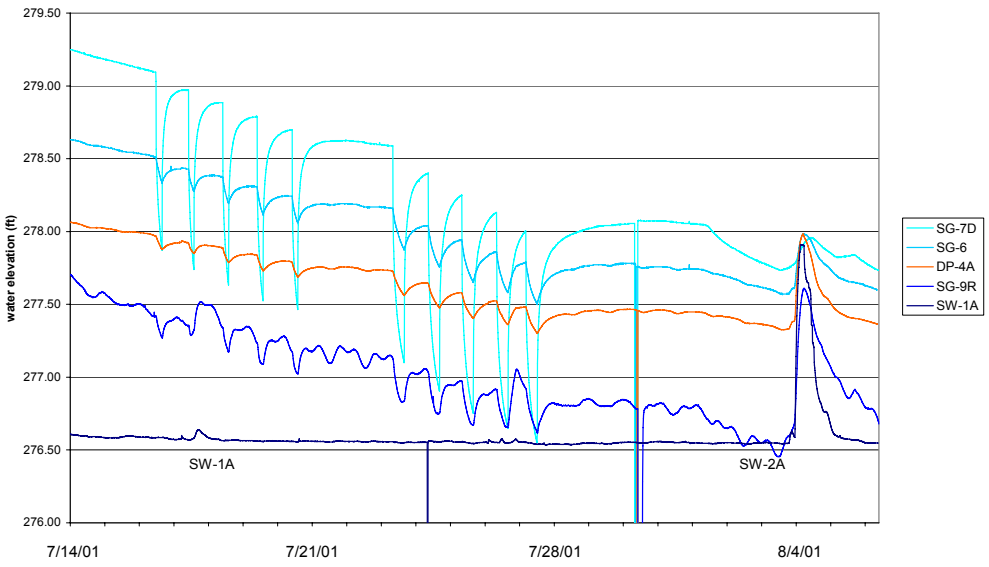

Figure 10. Water elevations measured in monitoring wells located on the western side of the canal.

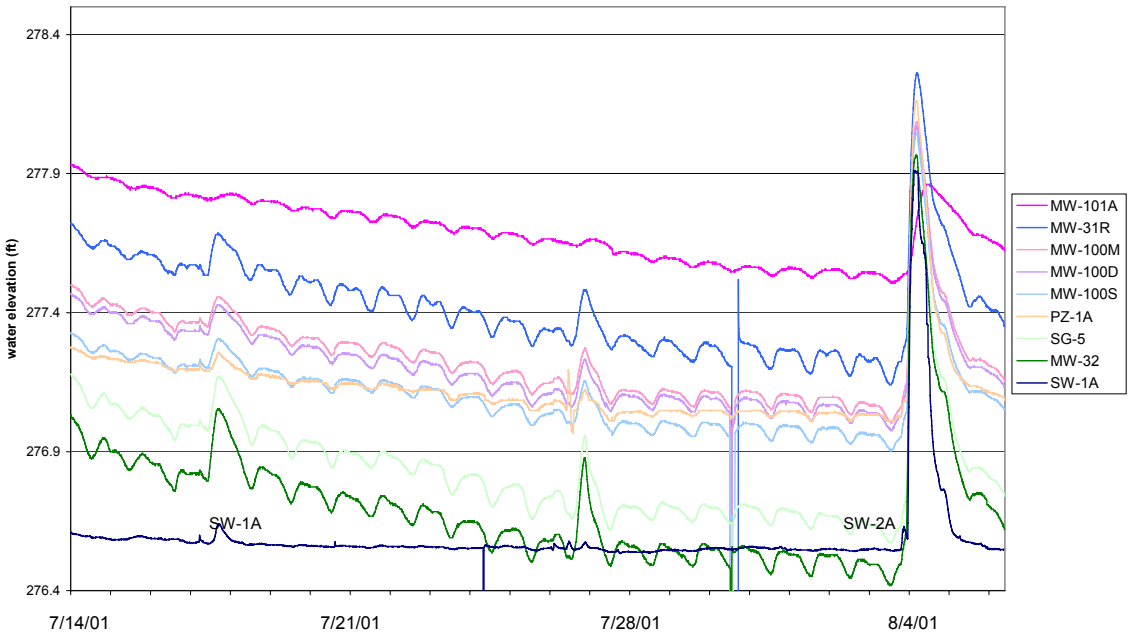

Figure 11. Water elevations measured in monitoring wells located on the eastern side of the canal.

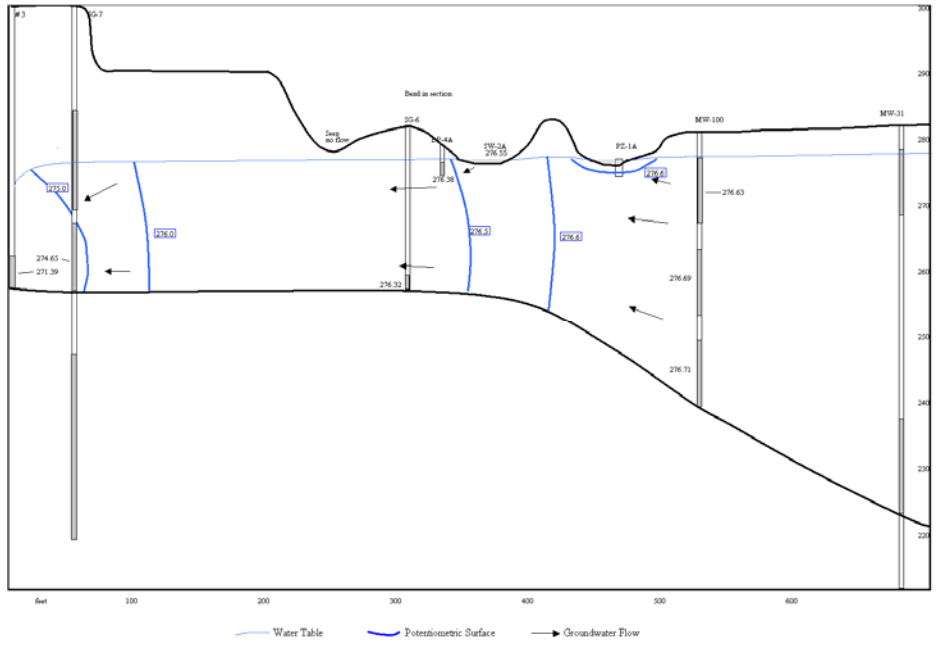

Figure 12. Potentiometric contours between SGWD Well #3 and MW-100S, M and D based on water elevations measured on July 16, 2001.

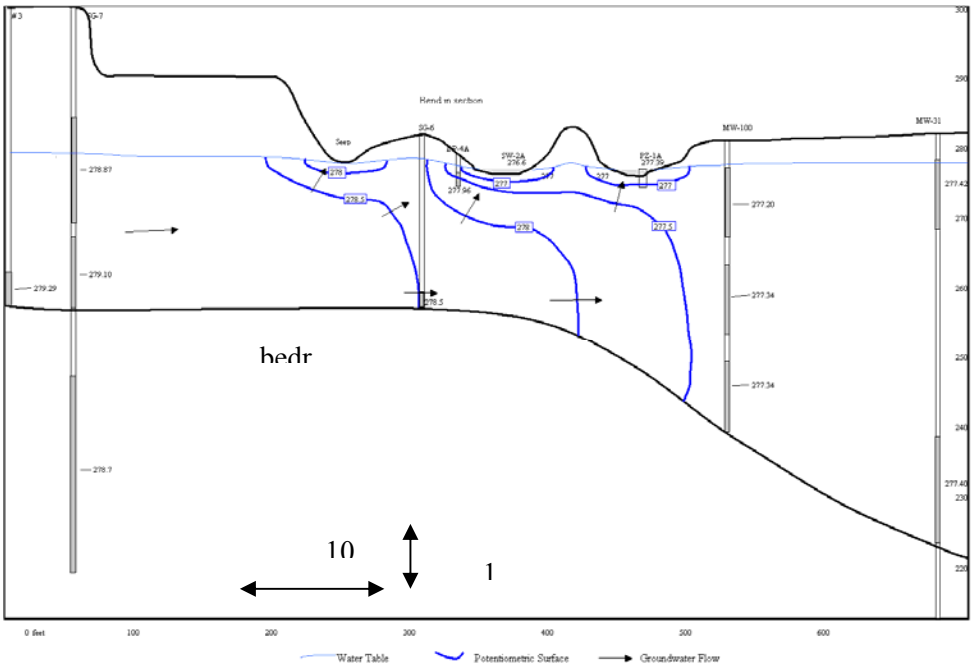

Figure 13. Potentiometric contours between SGWD Well #3 and MW-100S, M and D based on water elevations measured on October 25, 2001.

2.2.3 Conceptual Model

Based on the pumping tests, water level measurements, and groundwater sampling data, it appears that TCE migrated from a deep overburden source located under the western end of the former mill to Well #3. The PVDS study (Figure 8), vertical profiling results (Figure 9), surface water and groundwater sampling results, and gauging data (Figure 12) indicate that contaminated water in the shallow overburden aquifer discharges to the canal and that a deeper CVOC (mostly TCE) plume migrates to the south and southeast towards the Blackstone River during the wetter parts of the year. However, during the dry part of the year when Well #3 is in use, the deep plume shifts westward and is drawn under the canal (Figure 13). A bedrock pathway may be possible, but pumping Well #3 had little or no effect on groundwater elevations on the peninsula where bedrock contamination is known to be present and very high TCE concentrations would have to present in bedrock in the area of influence of Well #3 in order to be detected in water produced from Well #3. Based on sampling results for DP-4A it also appears unlikely that CVOCs are migrating towards Well #3 via a shallow pathway. However, it is possible that shallow contaminated groundwater from the eastern side of the canal could migrate underneath DP-4A. It is uncertain why TCE was not detected in a sample collected in November 2000 from SG-7D. However work conducted in the former mill has shown that there are strong preferential pathways in the overburden aquifer.

3. RISK REDUCTION

In June 2000, the EPA SITE program and CMEDA initiated a pilot study evaluating use of Hydrogen Release Compound (HRC®, Regenesis, 2004) to treat the CVOC plume. Monitoring well MW- 1D is located immediately upgradient of the HRC® injection area and sampling results (Figure 14) are typical of results from the treatment zone. After trichloroethene was detected in SGWD Well #3 in November 2000, the EPA and MassDEP determined that reduction in contaminant mass within the Fisherville Mill source area was needed to reduce TCE concentrations in groundwater on the peninsula to levels that would no longer represent a threat to the well field. Because high concentrations of cis-1,2-dichloroethene were still present more than one year after injection of the HRC®, MassDEP, EPA, and SGWD concluded that other risk reduction measures would be required to minimize risk to Well #3.

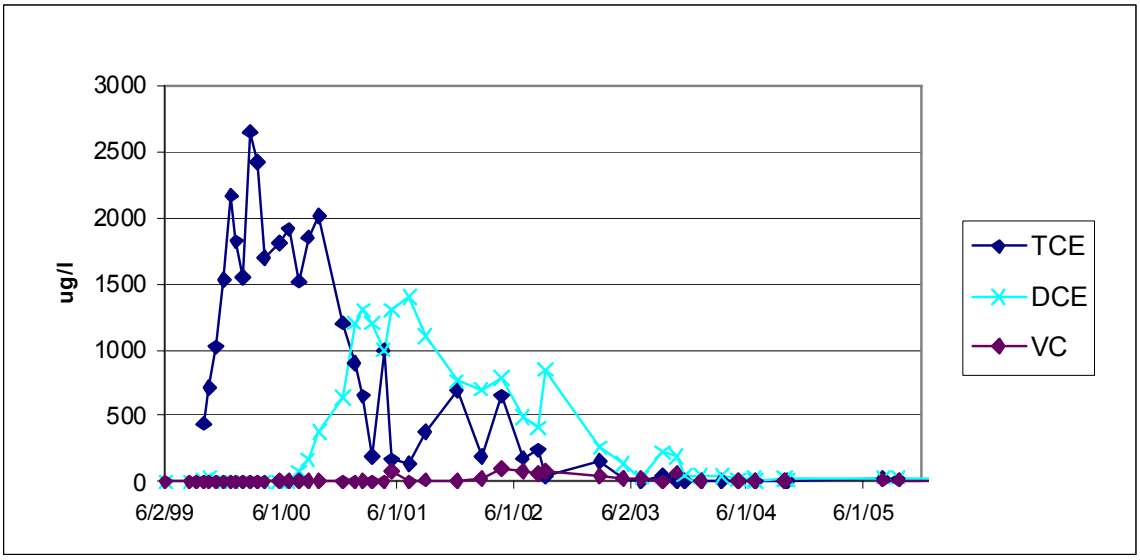

Figure 14. Trichloroethene (TCE), cis-1,2-dichloroethene (DCE) and vinyl chloride (VC) concentrations measured in groundwater samples from monitoring well MW-1D.

Based on TCE concentrations, the project team concluded that residual DNAPL in the deep overburden and shallow bedrock under the western end of the former mill was the most likely source of groundwater contamination threatening SGWD Well #3. Calculations by the project team suggested that a reduction of dissolved TCE concentrations in source area groundwater by two orders of magnitude would reduce down-gradient concentrations to the point that the SGWD well field would no longer be threatened.

After evaluating several remedial options including enhanced in-situ bioremediation, groundwater extraction and treatment, and point of withdrawal treatment, In-Situ Chemical Oxidation (ISCO) was selected by the project team as the preferred alternative. ISCO treatment would destroy contaminant mass in the source area resulting in eventual decreases in the size and contaminant concentrations of the downgradient plume. However, based on the seepage velocity across the site, it was anticipated that there would be a delay in achieving improvements to downgradient water quality, so a temporary method of protecting the SGWD well field in the

near term was needed. A temporary dam was constructed in the Blackstone Canal to address this concern.

3.1 Temporary Dam

The EPA completed installation of a temporary sand bag dam (Figure 15) near the confluence of the Blackstone River and Canal south of the former Fisherville Mill (Figure 2) on June 28, 2002 and replaced the sand bag dam with a sheet-piling dam (Figure 16) during December 2003. The dam was installed to deflect the CVOC plume away from Well #3. Figure 17 shows potentiometric contours after the dam was installed. Average groundwater elevations, except for the area influenced by the dam, were similar on July 16, 2001 (Figure 5) and July 12, 2002 and comparison of Figures 5 and 17 illustrates the dam's effect on potentiometric gradients in the deep overburden aquifer. After installation of the dam, water elevations in monitoring wells near the canal (MW-1D, MW-100D) increased relative to monitoring wells located in the center of the peninsula (MW-29D, MW-31D, MW-32D). Installation of the dam enhanced flow to the east towards the Blackstone River. During the late summer of 2002, when water elevations in the canal dropped below the crest of the dam, potentiometric gradients were similar to pre-dam conditions. This pattern persisted until water levels increased during late October 2002.

Figure 15. Sand bag dam installed in June 2002.

Figure 16. Sheet-piling dam installed in December 2003.

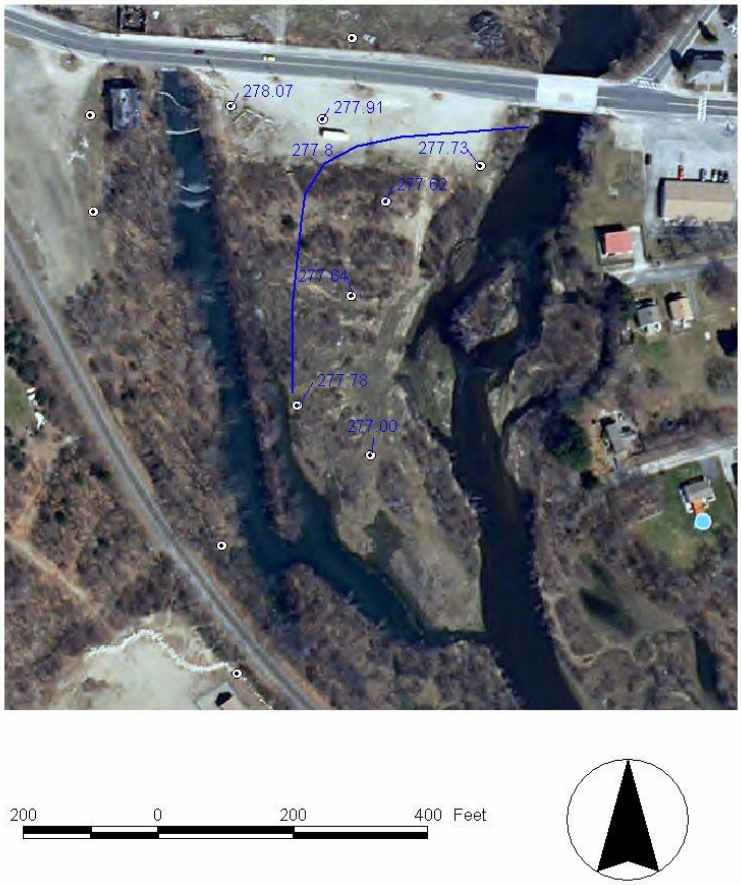

Figure 17. Potentiometric contour (277.8 ft) based on water elevations measured in deep overburden monitoring wells on July 12, 2002.

Gauging data for MW-31D and 100D are summarized in Figure 18. Gauging data for MW-1D and 29D exhibited a similar pattern. After the dam was installed in late June 2002, gradients between MW-31D and100D, and MW-1D and 29D reversed. Gradients reversed again in mid-August 2002 as water levels in the canal dropped and have reversed numerous times during the five years since the dam was installed. Water elevations in MW-100D and MW-1D were greater than elevations in MW-31D and MW-29D respectively during most of the winters, springs and early summers of 2003 2004 and 2005, and this pattern has been more persistent since a flood in October 2005 deposited up to two feet of sediment on the peninsula and deepened the Blackstone River channel. When the water elevation in MW-100D is higher than the elevation in MW-31D and the elevation in MW-1D is higher than in MW-29D (i.e. the difference is > 0 in Figure 18), the VOC plume migrates to the southeast away from South Grafton Water District (SGWD) Well #3.

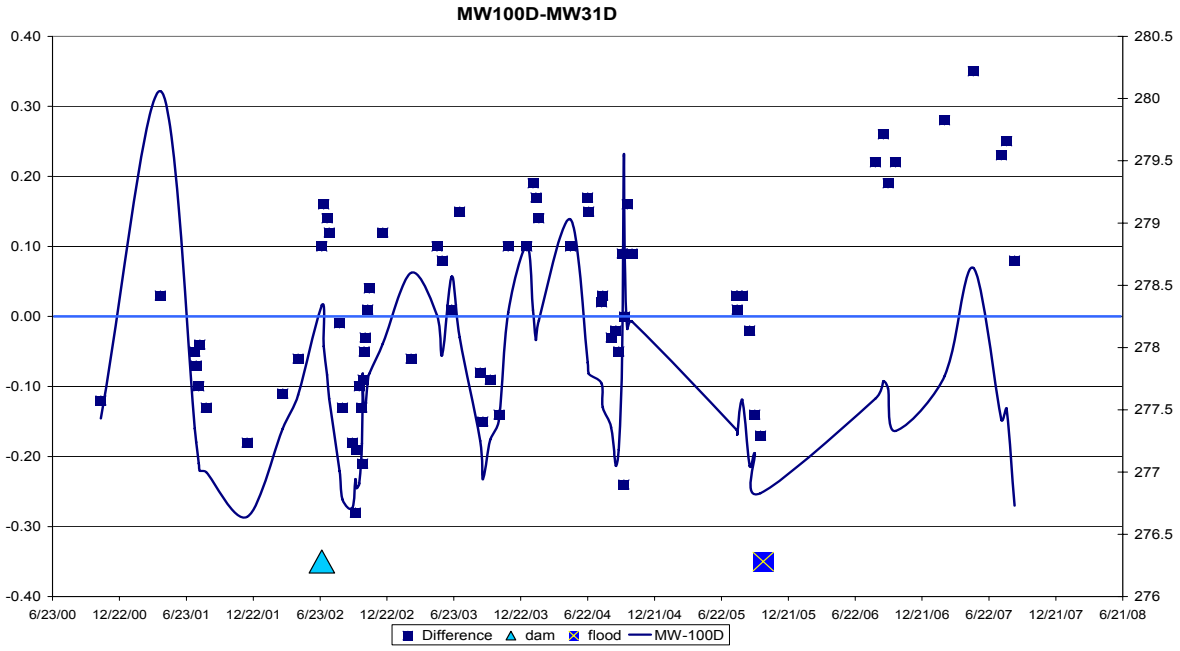

Figure 18. The difference in groundwater elevations between MW-100D and MW-31D and the groundwater elevation measured in MW-100D. The dam was installed on June 28, 2002 (blue triangle) and a major flood occurred on October 14, 2005 (dark blue square).

In the month following installation of the dam, TCE concentrations decreased in MW-1D, 31D and 100D. Concentration changes shown in Figures 14 and 19 are similar in all three wells. However, during the late summer of 2002 when water levels dropped below the crest of the dam and the SGWD started using Well #3, TCE concentrations increased in all three monitoring wells. After water levels rose in the winter and spring of 2003, TCE concentrations decreased in the three wells and remained low until the fall of 2003. The increases in concentrations during the fall of 2003 were less than in 2002. This was the case even though the SGWD pumped

approximately 226,000 gallons per day from Well #3 from mid-April to December 2003. TCE concentrations have been less than 1 ug/l in samples from MW-100D since January 2004 and less than 7 ug/l in samples from MW-31D since October 2004. A groundwater sample collected from monitoring well SG-6 on October 24, 2003 contained 1.9 ug/l TCE. TCE has not been detected in SG-6 since October 2003.

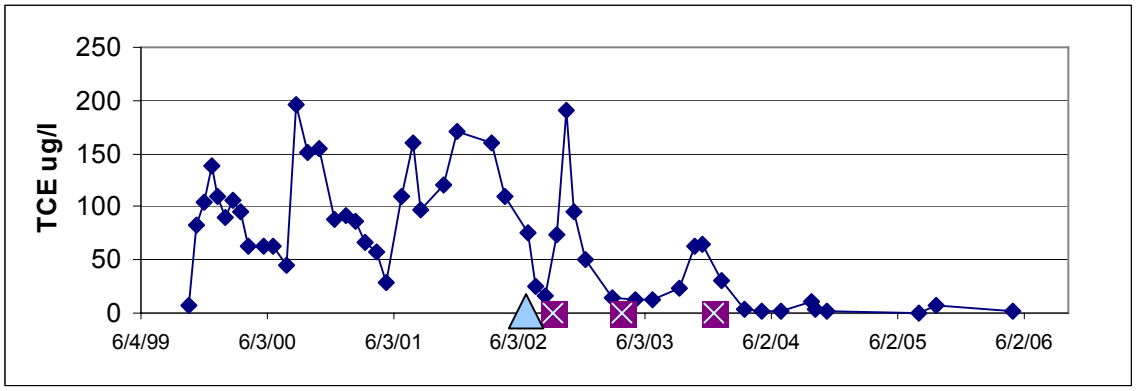

Figure 19. TCE concentrations measured in groundwater samples collected from MW-31D.

TCE concentrations in bedrock monitoring wells on the peninsula decreased in MW-1R and remained relatively constant in MW-31R (Figure 20). Monitoring well MW-31R is approximately 90 feet deep with a screen 15 to 30 feet below the bedrock surface. Based on polyethylene diffusion bag sampler results, contaminated water is present at the top of the screened interval. The different responses in MW-31D and MW-31R following installation of the temporary dam indicates that hydrologic changes in the overburden aquifer have little effect on contaminant migration in MW-31D.

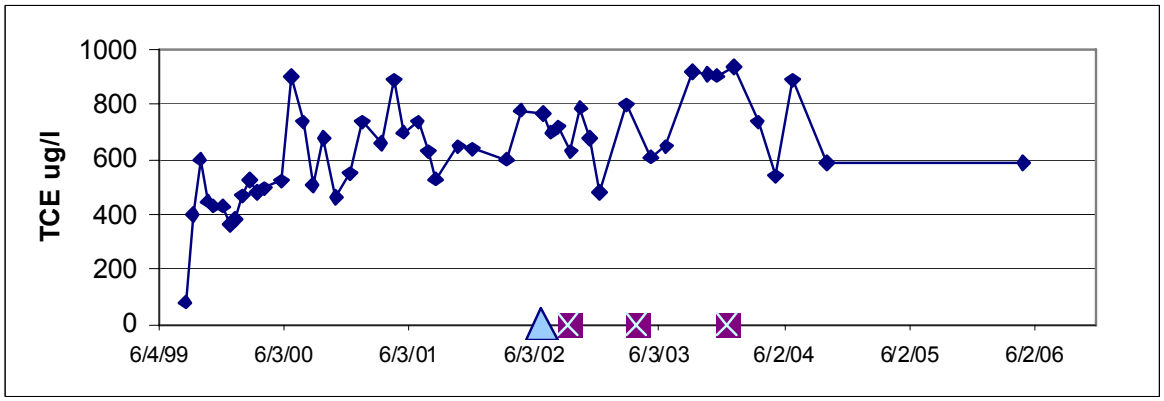

Figure 20. TCE concentrations measured in groundwater samples from MW-31R.

Total precipitation was greater during August, September and October of 2002-2006 than during 2000 and 2001. Because of this, it remains uncertain how effective the dam will be during dry years similar to 2000 and 2001. However, it does appear that a series of years with

near (2002, 2006) or above average (2003-2005) precipitation do have a cumulative effect and have minimized risk to Well #3. TCE was not detected in Well # 3 after November 2000 and the dam allowed use of Well #3 while ISCO was implemented in the source area.

4. IN-SITU CHEMICAL OXIDATION (ISCO)

The advantages of implementing ISCO as the long-term solution at this site were that it:

- Had been shown to be effective for the contaminants of concern (TCE and its breakdown products),
- Chemically degraded contaminants upon contact, without producing more toxic compounds like vinyl chloride,
- Could be implemented within the timeframe dictated by USEPA under the time-critical removal action program, and
- Did not require any long-term operations and maintenance, for which there was no funding or proprietor.

A number of chemical oxidants were evaluated for use at the site including hydrogen peroxide (or Fenton's Reagent), permanganate (either NaMnO4 or KMnO4), and ozone, but sodium permanganate was selected as the preferred approach. Sodium permanganate had several key advantages over the other oxidants considered including:

- Permanganate is more persistent in the subsurface than peroxide or ozone. Therefore, it has a wider range of options for field application/subsurface delivery.
- Because of the higher stability of permanganate, diffusive transport through low permeability zones, such as the till unit at the Fisherville Mill Site, is possible.
- Permanganate has a strong affinity for oxidizing organic compounds containing carbon-carbon double bonds, aldehyde groups, or hydroxyl groups. The other oxidants are less selective oxidizers. The effective radius of treatment will likely be greater for permanganate than it would be with other oxidants, because it is less likely to be consumed as quickly by natural organic matter in the subsurface.
- Permanganate is a more stable oxidizing agent, so dangers of rapid decomposition are not as great as with peroxide and ozone. However, fire or explosion hazards still exist if the permanganate comes in contact with combustible or flammable compounds.
- The optimum pH range for chemical oxidation with permanganate is 7 to 8, but it is effective over a wide pH range. Therefore, no pH adjustment is required.

- Laboratory and field studies have demonstrated that permanganate has the highest oxidation efficiency for destruction of TCE and PCE, as compared to Fenton's Reagent or ozone. (West, et al., 1997).

- The density of the proposed 20% sodium permanganate solution is close to that of the DNAPL contamination and thus would likely seek the same contaminant migration pathways through the subsurface, targeting residual DNAPL.

Permanganate can be applied to the subsurface in the form of potassium permanganate (KMnO4) or sodium permanganate (NaMnO4). Potassium permanganate is less expensive, but less soluble in water. Solutions of potassium permanganate can be readily mixed in concentrations of 3 to 4 % (by weight), whereas sodium permanganate is available in liquid form at a 40% concentration. The higher solubility of sodium permanganate increases the ease of application, reducing labor costs, and making it cost effective at some sites. However, because of the higher concentration of the NaMnO4 solution, there are greater health and safety concerns.

The reaction is as follows:

$2NaMnO_4 + C_2HCl_3 \Rightarrow 2CO_2 + 2MnO_2 + 2Na^+ + 2Cl^- + HCl$

Stoichiometrically, a ratio of 2:1 permanganate to TCE is required to oxidize TCE to carbon dioxide. However, laboratory studies have indicated that the reaction is optimized at a ratio of 5:1. (Dichloroethene and vinyl chloride are also amenable to oxidation by permanganate with stoichiometric ratios of 8:3 and 10:3, respectively.) The presence of naturally occurring organic matter and inorganic chemicals that exert an oxygen demand will further increase the dosage of oxidant required.

5. TREATABILILITY TESTING

5.1 Treatability Study

A treatability study was conducted in spring of 2002 to verify that sodium permanganate would effectively destroy the site contaminants, to determine the amount of oxidant required, and to evaluate various methods of delivering the oxidant to the subsurface. The treatability study consisted of 1) in-situ injection testing to evaluate injection rates and injection point design and spacing; and 2) bench scale treatability tests to evaluate the effectiveness of various doses of permanganate in destroying site contaminants.

The injection testing was conducted by injecting potable water into the subsurface using three different injection point designs including: 1) 1" diameter PVC well points installed using direct-push methods, 2) 2-inch diameter monitor wells installed using conventional rotary drilling methods, and 3) direct injection via direct push drilling rods.

The injection tests were performed by pumping potable water into a single injection point, and monitoring the injection flow rate, volume and backpressure. Water level measurements were also made in nearby monitor wells and injection points to assess the radius of the treatment zone. The injection was continued for 10 to 20 minutes based on the response of water levels in nearby wells. In most cases, a large rise in water levels (0.5 to 1-ft) in adjacent wells was noted within five minutes, with only slight increases (few hundredths of a foot) after that.

Of the various injection points tested, the 1-inch diameter PVC well point performed best. Although injection through the drill rods was possible at high flow rates (up to 20-gpm) with little or no back pressure, better water level response in adjacent wells was observed using the PVC well points. In addition, installation of PVC well points would enable them to be used as future monitoring points to help assess the effectiveness of the treatment and for subsequent oxidant injections, if deemed necessary.

The injection rates varied from 3-gpm to 23-gpm. The lower flow rates were confined to shallow injection points where the flow had to be reduced to prevent surface breakout of the injected water in the annulus around the well point. Intermediate and deeper well points were able to accept flow rates of 15 to 20-gpm with little or no backpressure. The volume of water injected into the intermediate and deep well points ranged from 250 to 450-gallons. The data indicated that the injection system and aquifer capacity would not be limiting factors for the oxidant delivery system design.

5.2 Bench-Scale Testing

To confirm the effectiveness of sodium permanganate at reducing site contaminants to below the cleanup goal and to assess the required dosage, a bench-scale treatability test was conducted. Four composite samples of site soil and groundwater were collected. The soil was collected using direct push drilling methods from the area of highest known contamination. Two of the composite samples were composed of outwash, and two were of till. This was done to account for potential differences in the amount of natural organic carbon between the two formations.

The treatability test was conducted by dividing the four composite samples into seven oxidation test jars labeled “a” through “g”. Each test jar contained 500 grams of soil and 180 ml of groundwater collected from the monitoring well that contained the highest observed concentration of TCE at the site (370,000 ug/L). The oxidation test jars were then treated with sodium permanganate in a range of dosages from 2 to 40g permanganate/kg of soil (approximately 5 to 120 lbs permanganate per cubic yard of soil)**.** Water samples were collected for VOC analysis from each composite soil sample prior to allocation into the oxidation test jars. VOC samples were also collected from each oxidation test jar one week after introduction of the sodium permanganate.

The results of the treatability testing showed that the required dosage to achieve the treatment goal (reduce the TCE concentrations in the source area by two orders of magnitude) is between 2 and 6-grams (g) of sodium permanganate for every kg of soil. Figure 21 shows the oxidation test jars from one of the composite samples. Water and soil samples from the concentrations of contaminants in two of the three water and soil samples that had been treated with a dosage of 2

g/kg were less than two orders of magnitude lower than the original concentrations. The concentrations of contaminants in all of the water and soil samples that had been treated with a dosage of 6 g/kg were two orders of magnitude lower than the original concentrations and, with the exception of one soil sample, were below the analytical detection limits.

5.2.1 Conceptual Design

Conceptual design of the full-scale ISCO application was conducted following completion of the treatability testing and based on its result.

The area targeted for application of the oxidant is shown on Figure 22 and was chosen based on soil and groundwater quality data collected during historical site characterization work. The treatment area was approximately 100-ft by 200-ft, with the long axis parallel and abutting the Blackstone Canal, and a southern terminus at Main Street. This area was considered a conservative estimate of all areas with groundwater and/or soil with concentrations greater than 1 mg/L total volatile organic compound (VOCs). A total of 100 injection points are included within the treatment area. The injection point grid consisted of 10 rows spaced 20-ft apart in the direction parallel to groundwater flow (roughly north to south). Each row consisted of 10 injection points spaced 10-ft apart in the direction perpendicular to groundwater flow (roughly east-west). The spacing of the injection points was greater in the direction parallel to groundwater flow because of the convective transport that will occur in that direction. Each row was offset from the previous row by 5-ft so that the rows did not line up in the downgradient direction. This was done to prevent untreated zones from developing between the injection points.

Figure 21. Sodium Permanganate Bench-Scale Treatability Testing

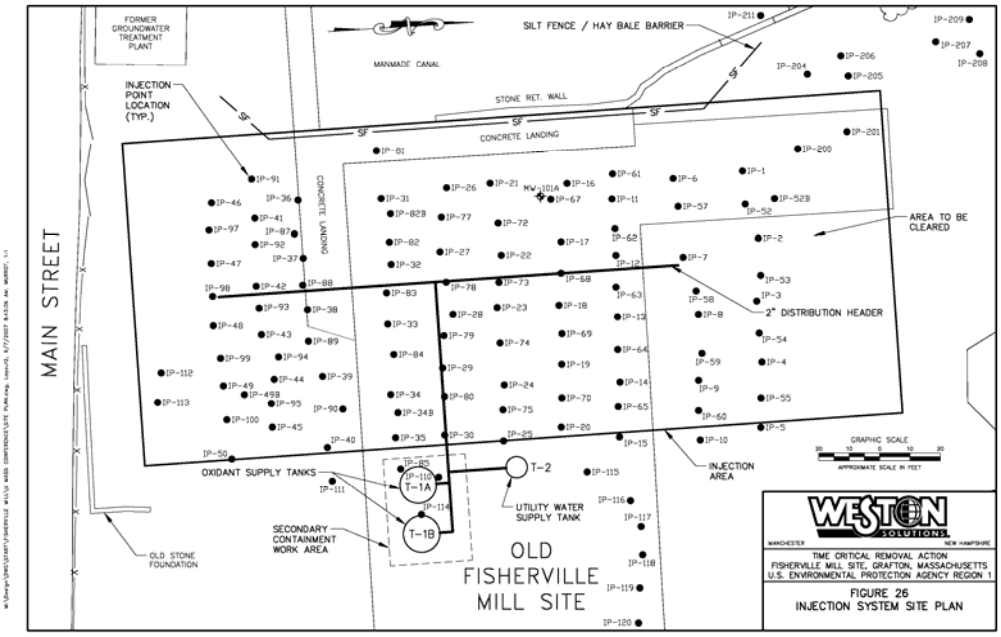

Figure 22. Injection System Layout

Based on the bench scale treatability test results, the recommended dosage rate was 4 g of sodium permanganate for every kg of soil. For purposes of full-scale implementation of ISCO at the site, this equated to injection of 1,244-pounds of $NaMnO_4$ per injection point. Permanganate dosage rates for ISCO are highly dependent on the amount of naturally occurring organic matter present in the site soils. During the treatability testing, soil samples were collected and analyzed for TOC. TOC concentrations in the untreated soil samples varied from 1,541-milligram/kilogram (mg/kg) in the till sample to 3,283-mg/kg and 4,483-mg/kg in the outwash samples. More than 50% of the TOC remained in the samples after treatment with permanganate. The relationship between soil TOC concentrations and permanganate demand was evaluated by Siegrist, et al. In the studies reviewed, the ratio of permanganate to TOC varied from 2-mg to over 100-mg of permanganate per milligram of TOC. Dosages of 2-mg to 10-mg permanganate per milligram TOC were most common. Increases in oxidant consumption were observed with increases in the oxidant dose concentration. Based on a minimum theoretical dosage of 2 mg permanganate per mg of TOC, and an average TOC concentration of 3,000 mg/kg, a theoretical dosage of 7.2 g $NaMnO_4$ per kg of soil, or 2,240-pounds of $NaMnO_4$ per injection point, was calculated. This is approximately 1.8 times the dosage estimated above, which is based on the VOC destruction observed during the treatability testing.

A direct calculation of permanganate demand per gram of TCE, DCE, and PCE was also made to evaluate the contaminant oxidant demand directly related to the site contaminants. The oxidant demands for TCE, DCE, and PCE are 1.81, 3.28, and 0.96-grams permanganate per gram of contaminant, respectively. This results in a demand of approximately 5 to 40 pounds of permanganate per injection point assuming a concentration of 9 to 40 mg/kg of TCE in the treatment area soils. Converting from the mass of permanganate ion (MnO_4^-) to the mass of sodium permanganate salt ($NaMnO_4$), this equates to 11 to 48-pounds of $NaMnO_4$ per injection point. This dosage is significantly less than the required dosage observed during the treatability

study because it does not take into account the oxidant demand of the naturally occurring organic materials in the soil. Less than 3% of the oxidant demand required to treat the soils at the site is likely to be directly related to the chlorinated contaminants.

Although the treatability study results provided valuable site-specific information regarding the mass of $NaMnO_4$ that would likely be required during full-scale implementation of ISCO, conditions varied throughout the treatment area. Therefore, the calculated dosages provided a good starting point for the full-scale design, but were not expected to predict exact oxidant demands for ISCO application. For this reason, it was recommend that application of the oxidant be conducted using a phased approach; with three or more injections. By injecting 50% of the calculated dosage during the initial injection, and 25% of the calculated dosage for subsequent injections, dosage rates could be adjusted based on performance. If monitoring indicated that concentrations of the contaminants had been attained, or were close to attaining, cleanup goals in certain areas, oxidant dosages injected in those areas could be reduced or eliminated. Conversely, if contaminant concentrations in some areas did not appear to be decreasing significantly, oxidant dosages could be increased in those areas.

5.2.2 Full-Scale Application of ISCO

Full-scale implementation of ISCO was begun in July 2002 with the installation of the injection points. The original design included installation and injection into 100 wells, however several injection points had to be relocated due to cultural interferences and one location was deleted altogether. To monitor the penetration of the permanganate into the bedrock, five bedrock wells (IP-52B, -82B, -34B, -49B, and MW-3T-B) were installed. Although direct push drilling methods were originally planned for installation of the injection points, they were ultimately installed using standard rotary drilling methods after it was determined that direct push methods were unsuccessful at reaching the design depth. The injection points are constructed of 1-inch diameter PVC with 10 ft of 10-slot well screen at the bottom, an appropriately-sized filter pack, and bentonite pellet seal installed 2 ft above the top of the well screen. The annulus was backfilled with native material to the ground surface.

Prior to full-scale injection of permanganate, a comprehensive baseline groundwater sampling round was conducted. This included sampling all 99 injection points and all accessible monitoring wells at the site. The injection point samples were analyzed for VOCs only, but the monitoring well samples were analyzed for metals as well as VOCs so that potential mobilization of metals by the oxidant could be assessed.

In August 2002 permanganate injections were initiated at the site with placement of the injection storage and pumping equipment including: three 6,500 gallon polyethylene storage tanks, three 250-gallon stainless steel tanks, two temporary containment structures, and two 3.5-horsepower centrifugal pumps. Two of the 6,500-gallon tanks used for the sodium permanganate solution storage were placed within containment structures. The third 6,500-gallon tank and the three 250-gallon tanks were utilized for clean water storage. Figure 23 is a schematic diagram of the injection system and Figure 24 is a photograph of the system as constructed.

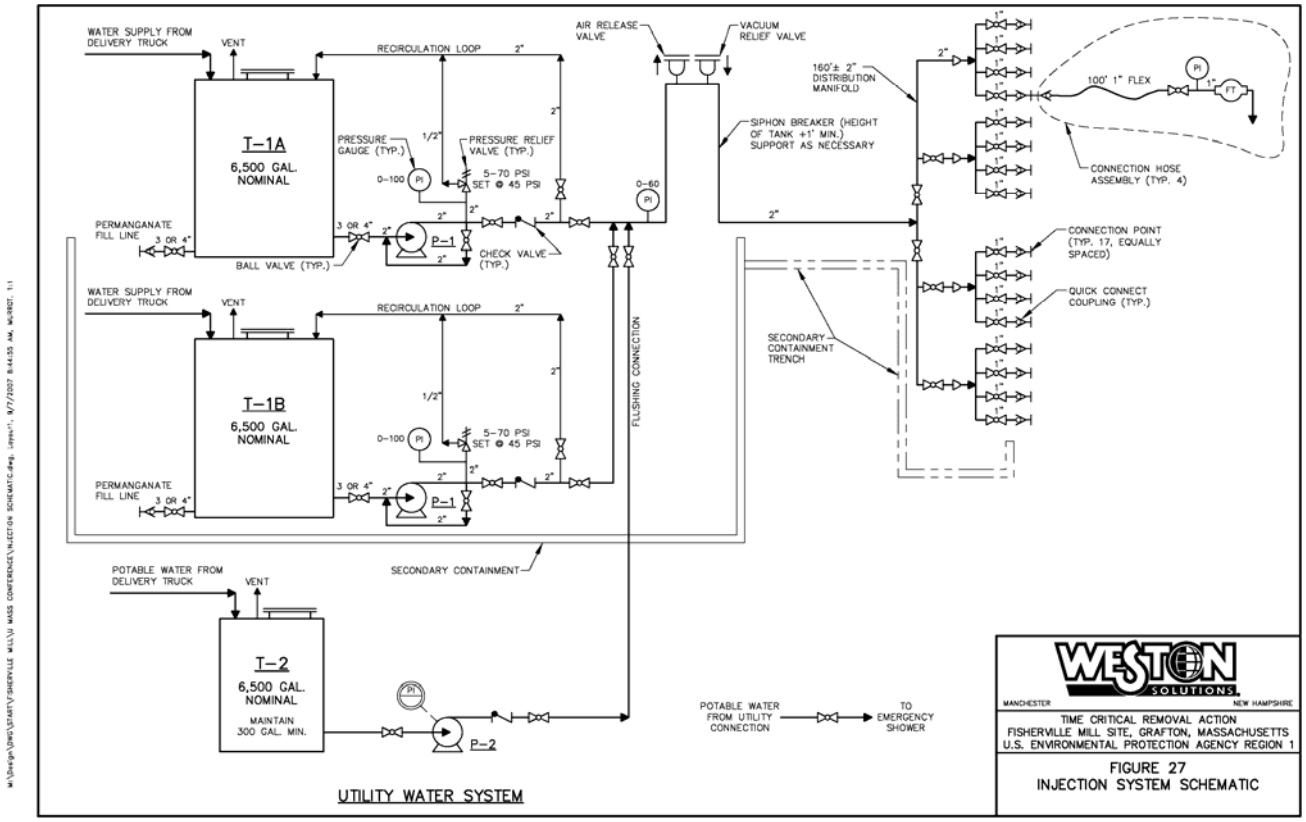

Figure 23. Injection System Schematic

Figure 24. Permanganate Mixing Tanks and Distribution Manifold.

After setup of the injection system, potable water was injected into a series of 4 injection points to test the equipment and to verify that the design injection rate of 10 gpm per well could be achieved. Water levels in adjacent wells were monitored to determine the extent of groundwater mounding caused by this injection rate. Minimal mounding was observed in adjacent wells, even after the complete injection volume of 373 gallons was injected into each of the 4 wells. The mounding dissipated within minutes after the injections were curtailed.

The first injection round began on August 28, 2002. A solution of 40% (by weight) sodium permanganate was delivered to two 6500-gallon polyethylene tanks at the site. The solution was diluted to 20% (by weight) before being injected into each of the injection points. A total of 373 gallons of the 20% solution was injected into each of the wells at a rate of about 10 gallons per minute, typically pumping into 4 to 6 wells at a time. A solution of 20% sodium permanganate contains 1.92 pounds per gallon, so each well received 716 pounds of pure sodium permanganate. This represents approximately 58% of the total design dosage.

The injection was begun at the upgradient (north) end of the treatment grid, working downgradient. Initially, the 20% sodium permanganate solution was injected into every other point in each row. After the first pass through the injection grid, oxidant was injected into the remaining wells, again progressing from upgradient to downgradient acres the grid. This “every other well” sequence allowed us to monitor for the presence of permanganate in the uninjected wells to evaluate permanganate distribution between injection points before completing the injection round. By the time injection of the first half of the wells was complete, permanganate was observed in the majority of the uninjected wells, indicating that the permanganate was quite well distributed throughout the treatment area.

Upon completion of the initial injection, permanganate levels were monitored in the injection points as well as in a series of monitoring wells located throughout and adjacent to the treatment area on a weekly basis. The monitoring wells included both overburden and bedrock wells. Once the permanganate concentrations dropped to less than 1% (10,000 ppm) in a sufficient number of points within the treatment area, samples were collected for VOC analysis using an on-site GC.

Permanganate concentrations remained very high in the center and downgradient portions of the treatment grid, but only trace levels of permanganate were observed south of Main Street. An increase in dissolved oxygen and oxidation/reduction potential (ORP) was noted in monitoring wells south of Main Street. The lack of significant migration of the permanganate was attributed to the fact that although the permeability of the aquifer is very high, the hydraulic gradient across most of the treatment grid is very low. It is likely that increased water levels in the Blackstone Canal after installation of the temporary dam decreased hydraulic gradients in the treatment grid. This set of conditions allowed high concentrations of permanganate to stay within the treatment area for an extended period of time, thereby facilitating diffusion into lower permeability layers within the formation.

Although permanganate was not injected in bedrock monitoring wells within and/or adjacent to the treatment area, permanganate did eventually migrate into the bedrock. Permanganate was first observed in bedrock monitoring wells in late September, about 1 month after the initial injection. By the end of October, nearly two months after the initial injection, permanganate was observed in MW-101A, the most highly contaminated well at the site. Permanganate then persisted in the bedrock for the duration of the project. MW-101A differs from the other source area bedrock wells in that it is extremely "tight" and has limited connection with the overburden aquifer. It remains uncertain how TCE migrated to MW-101A. Permanganate was detected in MW-101A but concentrations were significantly less that in other wells and VOCs have persisted even with low concentrations of permanganate. Because of the limited connection with the overburden aquifer and the lack of transmissive fractures, high concentrations of TCE measured in MW-101A were not viewed as a significant threat to SGWD Well #3.

After approximately 6 months of permanganate and VOC monitoring it was noted that while the majority of the treatment area still contained high concentrations of permanganate, several injection points in the northwest corner of the treatment grid no longer contained permanganate and that VOC concentrations had rebounded to near pre-injection levels. As a result, a second more limited injection was performed in March 2003. Approximately 100 gallons of 20% sodium permanganate was injected into 10 injection points (IP-1, IP-2, IP-3, IP-6, IP-7, IP-12, IP-52, IP-53, IP-57, and IP-63). Because of the limited size of this injection, the manifold system was not used and the permanganate solution was mixed in 55-gallon drums and gravity fed into the individual injection points. Weekly permanganate monitoring was resumed after the second injection was completed.

Shortly after this injection, permanganate was observed seeping into the surface water within the adjacent canal near the Main Street Bridge. This area is heavily contaminated with #6 fuel oil from a former underground storage tank associated with the mill. Upon entering the surface water, the permanganate was immediately reacting with the fuel oil and/or natural organics. Surface water samples collected from the canal and screened using the spectrophotometer did not

show detectable levels of permanganate. The permanganate seepage stopped after a few days and was never observed again.

In August 2003, approximately 1 year after the initial injection and about 6 months after the limited second injection, monitoring again suggested that the permanganate has dissipated within a number of injection points and monitoring wells in the northwest corner of the injection grid. Subsequent VOC monitoring confirmed that contaminant concentrations remained above 1 mg/L total VOCs in this area. Many of the wells now exhibiting VOCs were the same ones that had been subjected to the second permanganate dose in March 2003. It was suggested that impacted groundwater might have been migrating into the treatment grid from a previously unidentified upgradient source. To assess this possibility, a series of vertical profile borings were advanced to the north and east of the treatment grid. A Waterloo Profiler was used to collect discrete groundwater samples at 5-foot intervals. The samples were analyzed for VOCs using an EPA mobile laboratory. Although some TCE and its breakdown products was found in groundwater upgradient of the treatment grid, the concentrations were generally very low and did not exceed the cleanup goal. As a result, it was concluded that the injection points within the treatment grid where the permanganate did not persist as long as in other areas must be a zone of higher permeability where more flushing with upgradient groundwater was taking place, not allowing the permanganate sufficient contact time with contaminants adsorbed to the aquifer matrix.

Permanganate continued to persist in nearly 90% of the injection points at very high concentrations, which was viewed as positive because it allowed the oxidant to diffuse into the lower permeability layers within the aquifer and also allowed extended contact time with the contamination. However, the continued flushing of selected areas of the treatment grid was not allowing those areas to be adequately treated. As a result, it was decided that a temporary recirculation system would be implemented to move the permanganate from areas with high levels to the northwest corner, where the permanganate did not persist very long. The objective was to re-circulate approximately one pore volume of groundwater estimated to be contained within the aquifer beneath the injection grid.

The initial groundwater/permanganate re-circulation was conducted in October 2003. During a 2-week period, approximately 384,000 gallons of groundwater containing permanganate was re-circulated. The extraction and re-injection points were varied almost daily based on observations of permanganate concentrations, groundwater mounding, and injection point yields

In December 2003, MassDEP installed eight steel injection points (IP-116 through IP-123) east of the original injection grid using direct-push methods. These additional injection points were installed to investigate possible additional VOC source areas and serve as a line of permanganate injection locations to treat any VOC contamination flowing east from the injection grid. The steel injection points were installed to variable depths depending on refusal of the direct push equipment.

Based on the results of the vertical profiling and recirculation study, and continued permanganate and VOC monitoring since the second injection, a limited third injection of sodium permanganate was performed in December 2003. Approximately 100 gallons of 20% sodium permanganate was injected into 16 injection points (IP-6, IP-7, IP-11, IP-12, IP-16, IP-

21, IP-57, IP-63, IP-67, IP-116 through IP-120, IP-122, and IP-123). Weekly permanganate monitoring was resumed after the third injection was completed.

Lastly, in late December 2003, a second groundwater re-circulation event was conducted in an effort to transfer high permanganate concentration groundwater from the southern end of the treatment grid to flush IP locations that had received the third sodium permanganate injection. Between 5,000 and 7,000 gallons of permanganate-containing groundwater was re-circulated from southern injection points to IP-7, IP-116, IP-117, IP-118, IP-119, IP-120, IP-122, and IP-123.

6. RESULTS

The cleanup objective for the Fisherville Mill ISCO project was to decrease trichloroethylene (TCE) concentrations in the source area by two orders of magnitude, thereby reducing the size of the downgradient plume, and reducing the risk of drawing TCE into the downgradient municipal water supply wells. This meant reducing the average concentration of TCE in the overburden source area from approximately 4000 ug/L and average concentrations in transmissive source area bedrock wells from approximately 16,000 ug/L to less than 100 ug/L. In March 2003, six months after completing the first injection of permanganate, detectable concentrations of TCE remained in 10 of the injection points and concentrations in two points exceeded 1 mg/L. The second round of injections into the 10 injection points was conducted in April 2003. The third round of injections into 16 injection points was completed in December 2003. Upon completion, over 18,000 gallons of 20% sodium permanganate solution had been injected into the subsurface at this site. Performance monitoring confirmed that the cleanup objectives had been attained in both overburden and in all transmissive source area bedrock wells. An increase in sodium concentrations was observed in source area groundwater as a result of the injections, but mobilization of naturally occurring metals, sometimes cited as a potential concern with implementation of this technology, was not observed. Figure 25 shows the distribution of TCE in the source area before and after implementation of ISCO. Figure 26 presents graphs of the average TCE concentration within the treatment area in both the bedrock and overburden. Attainment of cleanup goals was achieved within 16 months of implementation of ISCO and the project was completed under the $2M budget.

6.1 Creating a shared vision: Recognizing shared goals

FRC recognized an opportunity in the Fisherville Mill remediation project to utilize its accumulated knowledge and operational experience to clean up a highly impaired property and return it to a valuable economic and community use.

Through extensive consensus building, public visioning and detailed collaboration between the project stakeholders and the company, agreement in principle with regard to our fundamental prerequisites for a successful cleanup project to be undertaken was achieved. The development of consensus on the remedial approach and end use vision of the site were the primary deciding

factors that motivated FRC to complete the acquisition of the property and begin implementing its remediation strategy.

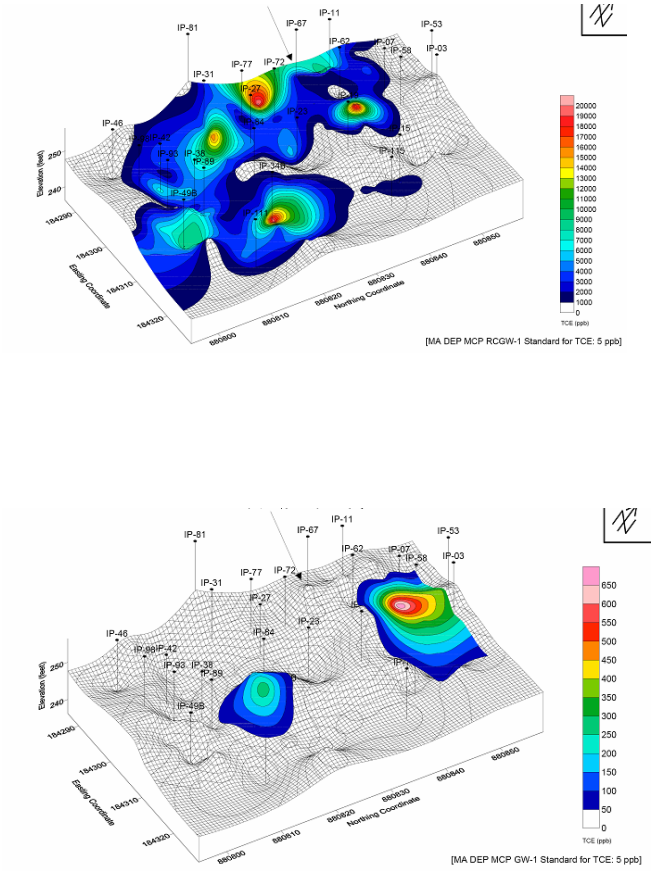

Figure 25. Distribution of TCE in Treatment Grid before and after ISCO (note change in concentration scale between figures).

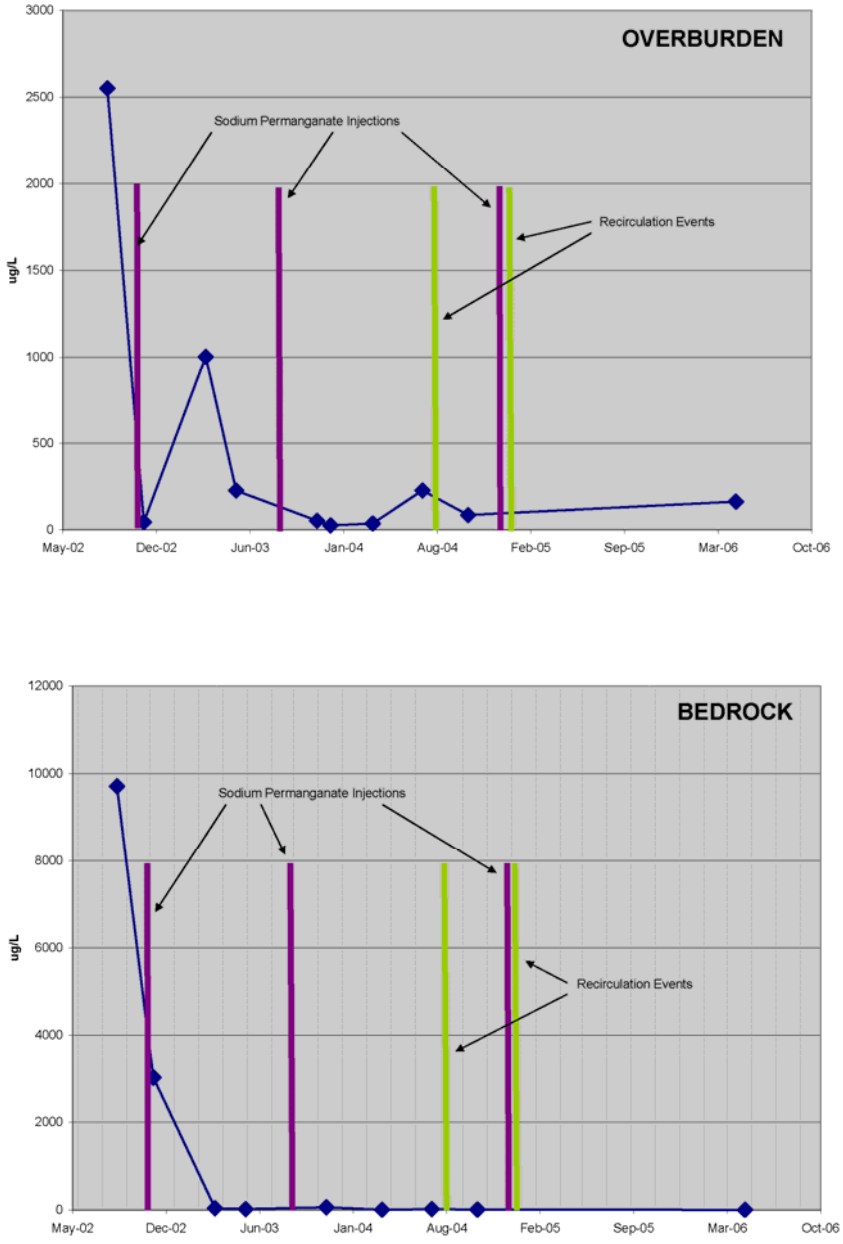

Figure 26. Average Total VOC concentration in source area in overburden and bedrock.

Figure 27. Rendering of mixed-use redevelopment of property with large amounts of open-space and public access for recreational activities.

To achieve the successful remediation and redevelopment of the Fisherville Mill site FRC recognized a need to create a vested community of regulators and public stakeholders with common goals and a shared vision. The implementation of complex cleanups and redevelopment projects in an adversarial or indifferent political environment are extremely difficult and often too risky for the private sector to undertake.

It was recognized that the dominant impediments to the cost-effective redevelopment of the Fisherville Mill site was the presence of tremendous volumes of visually offensive and environmentally sensitive asbestos impacted materials, poor underlying real estate value under then existing zoning, and time consuming and expensive regulatory requirements that would retard implementation of our remedial approach. Additional environmental impediments included the heavy metal impacted surficial soils, bunker oil contamination and residual CVOC contamination were also recognized but determined to be surmountable if the asbestos, zoning and regulatory issues could be adequately addressed. The primary source of the CVOC

contamination had been addressed by the implementation of ISCO by EPA in 2003 through 2005, as described in the second part of this paper.

Figure 28. Fisherville Mill Site before encapsulation with flowable fill.

In FRC's opinion, the key to establishing an effective collaboration lies in identifying and acknowledging the shared goals of the stakeholders in a cleanup project and creating a shared vision of final outcomes. In the case of the Fisherville Mill redevelopment project this involved the following:

- Developing a compelling end use vision
- Recognizing that the number one goal of all the stakeholders is a cleaned up site.
- Recognizing that the number one goal of most of the public is a visibly cleaned up site.
- Understanding the perceived value or lack thereof to the affected public of environmental engineering and the regulatory process.
- Focusing on implementing remedial activities wherever possible.
- Understanding and communicating owner / redeveloper risk

FRC determined that it would need to reach agreements on the following fundamental issues prior to assuming ownership of, and responsibility for, the cleanup of the Fisherville Mill Site:

- MassDEP agreement to allow encapsulation of the potential asbestos containing material at the site as an acceptable remediation strategy, thus allowing cost effective implementation of company remediation concepts.
- Town of Grafton agreement to pursue and support changing the underlying zoning for the site to allow higher value use by right, thus justifying remediation expense.

- MassDEP agreement to allow immediate remedial activities to be undertaken prior to completion of Phase 2 Comprehensive Site Assessment, thus allowing rapid tangible improvement in site economic value and appearance.

A collaborative approach and strategy was developed between FRC and our environmental consultants (Woodard & Curran), MassDEP, EPA, the Town of Grafton and several other stakeholder groups including, Mass Audubon, US Park Service, Mass Fish and Wildlife, Blackstone Heritage Corridor Commission and the Blackstone Headwaters Coalition, that would encourage significant remedial actions while environmental assessment and engineering design activities were ongoing.

The tangible benefits of our collaborative approach has been:

- An accommodating public with a vested interest in the success of the project and a willingness to tolerate truck traffic and noise associated with the remedial activities.
- Public support that encourages and facilitates a cooperative regulatory environment.
- A collaborative remedial strategy developed and supported through frequent communication and the shared knowledge and skills of site owners, environmental consultant and the regulatory community.
- Lower remediation cost due to:
    - Reduced filings: collaborative approach eliminates and or minimizes repeated submission of expensive environmental engineering documents and remedial approaches that may be unacceptable to the public, the owners and the regulatory community.
    - Efficient application of technical skills, knowledge and remedial actions.
    - Greatly reduced time to effect remedial outcome

The “on the ground” results of this approach has been:

- The expedited management of visible uncontaminated debris including bricks and steel.
- The encapsulation of the asbestos impacted debris and lead containing soil with flowable fill.
- The installation of a bunker oil interception and collection infrastructure.
- The clean up and partial restoration of a portion of the historic Fisherville canal.
- The removal and disposal of contaminated soil.
- The installation of soil vapor extraction piping infrastructure.
- The recovery and preservation of historic and architecturally valuable cut granite elements of the original mill building.
- The partial restoration Fisherville Dam.
- The re-grading, re-vegetation and stabilization of the site for future construction.

All of the above achievements have been realized without impeding the completion of comprehensive site assessment activities as dictated by the Massachusetts Contingency Plan (MCP). Additional site assessment activities conducted during the implementation of the remedial activities have focused on developing an accurate understanding of subsurface soil conditions in the CVOC source area, additional site investigation of the limits and extent of shallow CVOC impacted soils and evaluating options to complete remediation of the site. The remedial action plan is anticipated to be completed by the spring of 2008.

Additional innovative remedial alternatives that have been explored during this period include completing a pilot study that has demonstrated that fungi and higher plants may be a feasible approach remediation of oil contaminated sediments and the oil impacted surface waters of the canal. This novel, in-situ, remediation concept involves the use of selected higher plants and fungi in an engineered ecosystem that is capable of metabolizing petroleum compounds and converting them to living biomass.

6.2 Encapsulation of Debris with Flowable Fill

Though significant money had been spent by the EPA and MassDEP, CMEDA and others to stabilize the site and remove grossly contaminated waste immediately following the 1999 fire; enormous piles of asbestos containing materials containing, ash, contaminated soil, wood, steel, brick, concrete debris as well as remnant piping, machinery, and foundations virtually covered

Figure 29. Debris piles at Fisherville Mill before remediation

the entire site. As the cleanup of this visual and environmental blight was the highest priority of the community expressed during the consensus building process, the company determined that addressing this problem should form the foundation of the remedial approach at the site. Immediately addressing this high visibility issue at the outset of the remediation process reinforced and validated the company's core remedial concept of rapidly implemented improvement in site environmental conditions from both a public and regulatory perspective.

As the various debris materials were intermixed, the high costs for disposing of these materials without segregation and safety risks associated with their re-handling and segregation had prevented other interested developers in taking on this project.

FRC believed that it could best address this challenge and achieve multiple related goals in the redevelopment process through encapsulation of the asbestos impacted soils and debris in "flowable fill", an engineered low strength semi-liquid pozzolanic material.

The application of flowable fill to encapsulate the debris would accomplish the following:

- The desired immediate improvement in the visible appearance of the site.
- Immediate reduction in the potential environmental hazard posed to the public and site personnel from airborne asbestos.
- Reduction in the costs, risk, and complexity associated with excavation and disposal of potential asbestos impacted material at an off site facility.
- Creation of a high strength, level, subsurface pad suitable for use as a foundation for a multistory residential mill complex.
- Reinforcement of the earthen Fisherville Mill Dam allowing future re-watering of Fisherville Pond that in turn would improve subsurface hydrological conditions at the site by providing a constant water supply for the Blackstone canal.

By working with various regulatory officials, it was agreed that the application of flowable fill to encapsulate debris was a much better, safer method to handle the asbestos impacted material at this site.

In the first twelve months of the remediation project the former foundation holes of the mill buildings and the associated debris were encapsulated with a commercially available flowable fill product. A few discrete areas of debris piles with heights that exceeded the depth of flowable fill were relocated under a MassDEP approved asbestos work plan that included the use of wetting techniques and perimeter monitoring for asbestos fibers.

To prepare areas for flowable fill, concrete slabs were removed both to explore for pipes, tanks or other unknown sources of contamination but also to access vaults and voids for filling. Additionally, berms were created using soil to contain the flowable fill until setting. As described in further detail below, off-site soil from regional construction projects was evaluated by Woodard & Curran (W&C) for suitability, in accordance with soil acceptance criteria approved by MassDEP, and used at the site to form many of the berms.

Figure 30. Encapsulation of debris with flowable fill.

The flowable fill was prepared on-site using a portable batching systems in general accordance with the Massachusetts Highway Department (MHD) specifications for Type 1E (very flowable and excavatable) Controlled Density Fill as described in the December 11, 2002 "MHD Supplemental Specifications for Highways and Bridges" in subsection M4.08.0. The materials for flowable fill were processed in a mobile batching plant in an elevated location immediately adjacent to the application area. The flowable fill pours directly down the chutes from the portable batching system. The flowable fill is self-leveling and generally does not require any grading or reshaping to fill each application area.

Figure 31 (left). Application of flowable fill to encapsulate debris. *Figure 32 (right).* Flowable fill after setting and curing.

Infrastructure for a soil vapor extraction (SVE) system was installed in the shallow overburden soil in the front foundation area to allow for the potential future treatment of this area by SVE, as necessary. Due to the presence of shallow groundwater in this area, SVE wells were installed in a horizontal configuration. Vertical risers were run to the top of the foundation wall and capped. Existing monitoring and injection wells were extended above the final grade of the flowable fill to allow access for future monitoring and remedial actions.

Figure 33. Application of flowable fill in front foundation area in conjunction with SVE piping, monitoring wells and injection points.

6.3 Innovative Oil Control and Recovery

Since FRC's purchase of the property in 2004, one of the areas of the site that required continuous attention was the accumulation of bunker (No. 4 and No. 6) oil in the canal. Underground storage tanks (USTs) adjacent to the canal, used by the former mill owners were found to have leaked and were removed from the site in 1987. Subsurface investigations conducted on the fuel oil release area determined that there were large volumes of oil-saturated soil at depths of 10 to 25 feet below the ground surface adjacent to the vertical granite block canal walls. Massive granite blocks used as former building foundations limited excavation of these soils due to the risk of collapse of the canal walls. It had been observed that oil was seeping into the canal through gaps between the granite blocks within a fairly localized, 50-foot span adjacent to the western tailrace.

In 2004, the primary oil recovery technique was the containment of oil in the canal downstream of the tailraces, with absorbent booms and the periodic skimming of accumulated oil with a vacuum truck. This technique was expensive, labor intensive, and prone to occasional failure if there were large volumes of water flowing through the canal.

Figure 34. Oil absorbent boom change out in canal near tailraces

In 2005, a channel diversion wall and oil containment barrier was designed and installed at the canal tailraces. The diversionary structure routed canal water towards the eastern tailrace away from the source of oil at the western tailrace.

A platform was installed above the tailraces to allow for the installation of an adjustable hanging containment wall to contain floating oil for collection and allows water to pass under the wall. An Abanaki "Oil Grabber" belt skimmer was installed on the platform with the belt hanging into the containment area to skim oil. A section of drain piping surrounds the belt to prevent excessive movement due to wind or vibration.

Two recovery wells were installed using sections of perforated concrete leaching basins in an area adjacent to the location of the former USTs. During excavation of the recovery wells oil saturated soil and oil were observed. The excavation area was backfilled with coarse stone and oil-impacted soil was segregated for off-site disposal. Following installation, the recovery wells were fitted with Abanaki belt skimmers.

6.4 Cost Effective Re-use of Off-Site Soil

Off-site soil was reused at the site as berm, grading, shaping and cover material. Though approximately 30,000 cubic yards of flowable fill was used to encapsulate the debris, significant volumes (approx. 30, 000 cubic yards) of off-site soil was needed to create the berms, to cover above the flowable fill, and as grading material in transitional areas. As the cost to purchase virgin fill materials would be cost-prohibitive, a creative approach was developed for accepting off-site soils (that met MCP S-1/GW-1 standards) from urban construction sites.

Figures 35 and 36. Channel diversion wall installed in 2005 to direct canal water away from the oil-impacted western tailrace.

Figures 37 and 38. A containment wall was installed at the western tailrace to corral the oil and allow for collection with a belt skimmer.

Figure 39(left). Installation of one of two recovery wells using perforated leaching basin sections.; *Figure 40(right)*. Recovery wells fitted with belt skimmers.

FRC's and W&C's experience and existing relationships with business partners on similar projects provided the framework for a soil acceptance program that could be implemented at this site. FRC required generators of soil to characterize soil in accordance with acceptance criteria approved by the MassDEP. The acceptance criteria, required documentation of the source of the soil including a review of the historical use of the construction site and specific analytical testing requirements. The analytical results were compared to a set of acceptance standards developed for the site.

Prior to acceptance of soil at the site, a representative of W&C reviewed the analytical data, shipping records and opinion statements from the generator, to ensure conformance with the requirements outlined in the MassDEP approved soil acceptance criteria.

Figure 41. View of the site to the northeast across Main Street following application of flowable fill and re-use of offsite soil.

7. ACKNOWLEDGEMENTS

Dr. Paul W. Ollila was originally the corresponding author of this paper before he passed away on May 19, 2008. The Fisherville Mill Project Team dedicates all our efforts in the memory of our beloved friend. Dr. Ollila graduated from the Wachusett Regional High School in 1967 and the University of Rochester in 1972, where he earned a BA in Fine Arts. He received a Ph.D. in Geology from the University of Massachusetts Amherst in 1984 based on his work mapping the Santanoni Quadrangle in the Northern Adirondacks. Dr. Ollila taught at Vassar College, worked in environmental consulting, and served as a contractor for the Massachusetts Department of Environmental Protection. He was prolific in his field, presenting at professional conferences and publishing multiple articles on geologic and geo-chemical topics. Dr. Ollila contributed tremendously to the Fisherville Mill project, both as a leader and friend. We will miss him greatly!

8. REFERENCES

Church, P.E., Vroblesky, D.A., Lyford, F.P., and Willey, R.E. 2002. Guidance on the Use of Passive-Vapor-Diffusion Samplers to Detect Volatile Organic Compounds in Ground Water-Discharge Areas, and Example Applications in New England: United States Geological Survey Water-Resources Investigations Report 02-4186.

Desimone, L.A. and Barlow, P.M. 1995. Water-Quality and Hydrologic Conditions at a Site of Ground-Water Contamination by Volatile Organic Compounds, South Grafton, Massachusetts, September and October 1994. U.S. Geological Survey Open-File Report 95-425

Handex (Handex Environmental, Inc.). 1997. Comprehensive Site Assessment, Fisherville Mill, Route 122A, Grafton, Massachusetts. July, 1997.

HMM (HMM Associates, Inc.). 1993. Investigation of Groundwater Contamination Final Report; Prepared for MADEP. March, 1993.

ITRC. 2004. Technical and Regulatory Guidance for using Polyethylene Diffusion Bag Samplers to Monitor Volatile Organic Compounds in Groundwater: Interstate Technology and Regulatory Council. February, 2004.

Pine & Swallow Associates 2000a. Limited Subsurface Investigation, Fisherville Mill Grafton, Massachusetts. December 2000.

Pine & Swallow Associates 2000b. Fisherville Mill, Grafton, MA, PSA Reference Number: 00210. August 2000.

Regenesis, Inc. 2004. Case Study H-118. Regenesis, 1011 Calle Sombra, San Clemente, CA.

Siegrist, R.L., M.A. Urynowicz, O.R. West, M. L. Crimi, and K.S. Lowe (2001). Principals and Practices of In-situ Chemical Oxidation Using Permanganate. Batelle Press, Columbia NJ.

USEPA. 1998. Headspace screening for volatile organic compounds in aqueous, soil, and drum samples: Region I, Internal Standard Operating Procedure no. EIAFLDVOA1. SOP, U.S. Environmental Protection Agency, March 1998.

West, O.R., S.R. Cline, W.L. Holden, F.G. Gardner, B.M. Schlosser, J.E. Thate and D.A. Pickering. 1997. A Full-scale Demonstration of In Situ Chemical Oxidation Through Recirculation at the X-701B Site: Field Operations and TCE Degradation. ORNL/TM-13556. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Weston (Roy F. Weston, Inc.) 2002. Removal program Hydrogeologic Investigation Report for the Fisherville Mill Site Grafton, Massachusetts May 2001 Through December 2001; Prepared for U.S. EPA Region 1 Emergency Planning and Response Branch, Contract No. 68-W-00-097; April 2002.