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Subject:
Draft Focused Corrective Measures Study
Main Manufacturing Area
Watervliet Arsenal, Watervliet, New York

Date:
January 28, 2011

Dear Ms. Barraza:

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On behalf of the Watervliet Arsenal (WVA), enclosed please find one hard copy of the draft Focused Corrective Measures Study for the Main Manufacturing Area of the Watervliet Arsenal. .

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Please contact JoAnn Kellogg of the WVA at 518.266.5286, or me at 518.250.7359, if you have any questions.

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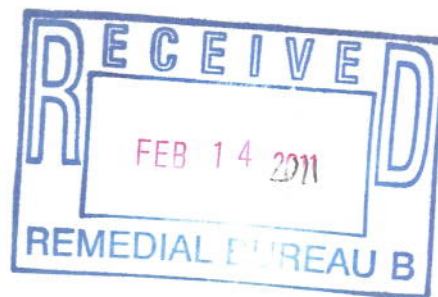
Sincerely,

Our ref:
02118177.0000



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Watervliet Arsenal

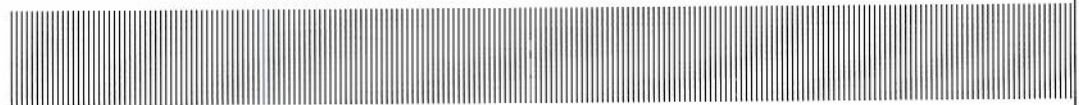
Watervliet, New York

DRAFT

Focused Corrective Measures Study

**Main Manufacturing Area
Watervliet Arsenal
Watervliet, New York**

January 2011



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Report Prepared For:

U.S. Army Corps of Engineers

Baltimore District, Baltimore, Maryland
Contract No. DACA31-94-D-0017



**US Army Corps
of Engineers**

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**MALCOLM
PIRNIE**

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1. Introduction

1.1. Purpose of Report

A Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) was conducted at the Main Manufacturing Area (MMA) of the Watervliet Arsenal (WVA) in Watervliet, New York from 1995 through 2001. The RFI was conducted in accordance with an Administrative Order on Consent between the WVA, the New York State Department of Environmental Conservation (NYSDEC), and the United States Environmental Protection Agency (USEPA) Region 2. The results of the RFI were presented in the *Final RCRA Facility Investigation Report, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated November 2000 (Final RFI Report) (Malcolm Pirnie 2000a).

Subsequent to the completion of the RFI, a Corrective Measures Study (CMS) was initiated by the WVA to identify, evaluate, develop, and recommend remedial alternatives for the areas of the MMA requiring corrective measures. As a preliminary step in the CMS process, additional investigations were conducted after the completion of the RFI to further understand the nature and extent of contamination. These investigations included:

- Soil, groundwater, soil vapor, and indoor air investigations at Building 40.
- Soil, groundwater, soil vapor, and indoor air investigations at Building 25.
- A soil vapor and indoor investigation of 25 buildings within the MMA and three off-site residential buildings adjacent to the MMA.

Following these investigations, bench, field-scale, and full-scale pilot studies were performed to evaluate corrective measures for these areas. Interim corrective measures (ICMs) were also performed for groundwater and indoor air at Building 40 and for indoor air at eight other MMA buildings.

The purpose of this report is to present the results of the preliminary screening of corrective measures technologies identified, and the final corrective measures developed, for the Solid Waste Management Units (SWMUs) located in the MMA. This report also addresses the final corrective measures for the unnamed SWMU for vapor degreaser units (SWMU - Vapor Degreaser Units), which includes the vapor degreasers formerly located at Buildings 20, 25, 40, 110, 120, and 130, as well as vapor intrusion into MMA buildings, which was a new requirement after completion of the RFI.

The final corrective measures were selected based on an evaluation of technical, environmental, human health and institutional concerns, as well as the results of bench and field/full-scale pilot studies and interim corrective measures.

1.2. Site Location and Background

The WVA is a 140-acre government-owned installation under the command of the U.S. Army Tank-Automotive and Armaments Command (TACOM). Located in the City of Watervliet, New York, the WVA is situated on the western shore of the Hudson River five miles north of the City of Albany, as shown on Figure 1-1. The WVA is a national registered historic landmark, which was established in 1813 with the purchase of 12 acres of land by the U.S. War Department. It currently consists of two primary areas: the MMA (125 acres), where manufacturing and administrative operations occur, and the Siberia Area (15 acres), which is primarily used for the storage of raw and hazardous materials, finished goods, and supplies brought from the MMA. These areas, as well as Buildings 20, 25, 40, 110, and 121, are shown on Figure 1-2. The WVA currently manufactures large caliber cannons and mortars.

The MMA is bounded on the east by Broadway Street (Route 32) and a six-lane highway (I-787), which separate the WVA from the Hudson River. Residential/light commercial properties are located along the northern and southern site boundaries. To the west of the MMA are: residential properties; the Siberia Area of WVA, which extends into the Town of Colonie; commercial properties; lands formerly owned by the Delaware and Hudson Railroad; and Canadian Pacific railroad tracks.

1.3. Physical Setting

The physical setting of the MMA is discussed in detail in the RFI Report (Malcolm Pirnie 2000a) and summarized below.

1.3.1. Geology

Surface soils at the MMA have been mapped by the National Cooperative Soil Survey (NCSS) as one of three distinct units. Surface soils in the southern and western portion of the site, the area where the majority of manufacturing activities occur, have been classified as “Ur”, or “urban land”. The northeastern portion of the MMA, containing the majority of residences, the golf course, swimming pool area, and a softball field is classified as “NaB”, or “Nassau channery silt loam, undulating.” The bedrock beneath these soils is very shallow, typically at a depth of sixteen inches. A small natural area in the block between AW-MW-22 and AW-MM-25 has been classified as “NaC”, or “Nassau channery silt loam rolling”. This soil is very similar to NaB and the only obvious difference is that it is typically found on slopes of up to 15 percent, while “NaB” is typically found on slopes of three to eight percent.

The major overburden unit identified in the MMA has been described as fill, consisting of brown or dark gray silty sand with angular gravel. The fill material is the only unit consistently found throughout the site, with the thickest amount of fill being in the eastern portion of the MMA. Underlying the fill are the following native overburden units: a fine grained alluvium, a coarser alluvium, and glacial till. These units are not present in all areas of the site.

The bedrock underlying the site is a black, medium-hard laminated shale, showing some characteristics of minor metamorphism. This shale has been identified as part of the Snake Hill Formation. The Snake Hill Formation has been described as heavily folded, and the effects of this have been noted during rock coring, as the shale displayed bedding planes at angles as high as 70 degrees. During coring, nearly vertical fractures were often encountered. The bedrock can be described in three ways based on the degree of weathering observed. The first is an extremely weathered zone approximately four feet thick. This extremely weathered bedrock unit is encountered at depths ranging from near ground surface to approximately 20 feet below ground surface (bgs). Beneath this extremely weathered bedrock is a zone of less weathered shale showing minimal competency. Competent bedrock is generally encountered at depths ranging from approximately 1.5 feet bgs on the bedrock divide to approximately 20 feet bgs on the eastern property boundary. Typically, competent bedrock was encountered at shallower depths and at higher elevations in the western portion of the MMA.

A borehole geophysical survey was conducted in 17 monitoring wells across the MMA to characterize the extent, orientation and magnitude of linear features (i.e., bedding and fractures) which intersect each of the well boreholes investigated. As part of the survey, Borehole Image Processing System (BIPS) high resolution panoramic video logging and standard video logging were used to identify fracture and or bedding plane magnitude and orientation. In addition, standard temperature and fluid resistivity logging were used to identify areas where groundwater recharge was occurring into the borehole. The primary direction of all linear features encountered in the well boreholes was to the east at an average dip direction of 100 to 110 degrees. These data corresponded to the direction of groundwater flow as delineated from water level measurements and discussed further below.

1.3.2. Hydrogeology

The majority of the MMA is relatively impervious to rainfall except at the residential and recreational areas of the northeastern portion of the WVA. Due to the shallow depth of bedrock and the limited amount of overburden in several areas of WVA, groundwater may be encountered within different geologic units (overburden, weathered bedrock, or bedrock) depending on the drilling location. For instance, groundwater is encountered in the bedrock at the western end of WVA (topographic high and local recharge area);

progressing eastward towards the Hudson River, groundwater is encountered in the weathered bedrock and then in the overburden deposits.

Groundwater flow in bedrock in the MMA is primarily controlled by the degree of fracturing within the bedrock itself and the local recharge area which is coincident with the topographic high. The most prominent feature on the potentiometric surface is a groundwater divide trending approximately north to south through Buildings 135 and 130. This feature appears to mirror a bedrock ridge. The primary discharge area for groundwater from the Main Manufacturing Area is to the Hudson River which is located to the east of WVA. For the area surrounding Building 25, groundwater in each of the hydrostratigraphic units flows from west to east towards the Hudson River, with a component of flow to the northeast. West of the groundwater divide, shallow groundwater flow discharges towards the Kromma Kill. Groundwater recharge occurs in the area of the bedrock ridge, resulting in consistently downward vertical gradients in this area. Groundwater flow in the eastern portion of the WVA, near the Hudson River discharge, exhibits generally upward vertical gradients.

2. Nature and Extent of Contamination

The nature and extent of contamination at the MMA is discussed fully in the RFI Report and is summarized below. Areas and media not discussed in the RFI Report are also summarized below, with reference to reports developed after the RFI was complete.

2.1. Summary of Solid Waste Management Units (SWMUs)

There are 24 named and additional unnamed SWMUs within the MMA. A summary of each SWMU is provided below. Corrective measures presented in this Focused CMS Report are related to SWMU No. 5 (Building 25), SWMU – Vapor Degreaser Units, and soil vapor intrusion, which is not a listed SWMU as it was a new requirement after the RFI was completed. A summary of all SWMUs is provided in Table and Figure 2-1.

2.1.1. SWMU No. 1: Sludge Drying Beds

There are five sludge drying beds at the industrial wastewater treatment plant, which was built in 1970 (Building 36) (Figure 2-1). In 1975, one of the beds was converted to an emergency holding tank that was determined to be a surface impoundment as stated in 40 CFR Part 260.10. Hazardous waste was stored in this bed for periods greater than 90 days, which necessitated the application for a Part B Permit upon the enactment of the RCRA regulations. WVA formally closed the bed in October 1987. Changes in the closure rules required additional soil removal for clean closure. WVA performed this additional work in January 1994. The NYSDEC accepted the clean closure in a letter dated May 3, 1994 and no further action was required.

2.1.2. SWMU No. 4: Demolished Cyanide Treatment Facility

The cyanide treatment facility (Building 110A) (Figure 2-1) was constructed in 1969 and put on-line in 1978. Cyanide treatment operations were relocated to the wastewater treatment plant, and the cyanide treatment facility was demolished, in 1981 during the Renovation of Armament Manufacturing (REARM) project. There were no known releases from the treatment tanks, and waste transfer lines, along with all of the building materials and cyanide treatment units, were shipped to a hazardous waste disposal facility upon demolition of the structure. Analytical results from soil and groundwater samples collected during the RFI indicated that elevated levels of cyanide were not present in the vicinity of the former facility. This SWMU was identified as not being a source of contamination and therefore no further actions were required.

2.1.3. SWMU No. 5: Building 25

A self-contained vapor degreaser unit located in the southeast quadrant of Building 25 (Minor Components Building) (Figure 2-1) was installed around 1970 and ceased

operation in 1982. The original degreaser used for cleaning small metal components in Building 25 was tetrachloroethene (PCE), which was eventually replaced by trichloroethene (TCE) and 1,1,1-trichloroethane (1,1,1-TCA). Potential releases of these chlorinated solvents to the soil and groundwater at Building 25 could have been through vents in the exhaust system, spills, and disposal of spent solvents. Chlorinated volatile organic compounds (CVOCs), including PCE, TCE, and 1,1,1-TCA were discovered in downgradient groundwater monitoring wells in 1986 and also in soil and groundwater samples collected during the RFI. Previous investigations at Building 25 are summarized in the RFI. A Pilot Study for treating groundwater containing elevated PCE and TCE concentrations east of Building 25 was conducted from 2001 to 2004. Details of this study are included in the *Pilot Study Report, Building 25 – HRC® Injection, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York* (Building 25 Pilot Study) (Malcolm Pirnie, 2006a) and summarized in Section 4.0 of this report. Other than long-term groundwater monitoring, no further action was required for this SWMU for soil and groundwater. Vapor intrusion mitigation for this SWMU is discussed separately in Section 5.

2.1.4. SWMU No. 6: Wastewater Treatment Plant

An on-site treatment facility (Building 36) (Figure 2-1) that treats mainly acid rinse waters (acidic chromium metal plating wastes) and soluble waste oil was constructed in 1969 and put on-line in 1970. In accordance with a RCRA exemption de-listing the waste, the sludge generated from the facility is dewatered and disposed in an industrial non-hazardous waste landfill. Treated effluent is discharged into the Hudson River (outfall 002) in accordance with a State Pollutant Discharge Elimination System (SPDES) permit. In January 1996, there was evidence of a leak in the underground single-walled transfer line from the indoor clarifiers to the outside sludge drying beds. Remedial actions included soil removals. In 1996, the broken transfer line was replaced with a 12,000 gallon waste soluble oil underground storage tank (UST). Analytical results from soil and groundwater samples collected during prior investigations indicated that RCRA-listed metals (i.e., chromium) were not present in the vicinity of the former facility. An extensive groundwater monitoring program is in place for the facility. No further action, other than long-term groundwater monitoring, is required for this SWMU.

2.1.5. SWMUs Nos. 7 - 14: Underground Waste Oil Storage Tanks

Eight USTs in the MMA were designated for waste oil storage, but were reportedly used to store hydraulic oil, lubricants, non-chlorinated degreasing solvents, chlorinated solvents, and skim oil, which were produced during various manufacturing activities that took place at WVA. Since September 1987, all eight USTs were removed and/or replaced. The USTs removed under SWMUs 11 and 12 were leaking upon removal. However, no significant residual contamination remained after removal and/or replacement of any of the USTs. No further action is required for these SWMUs. The location of the eight USTs is shown in Figure 2-1 and is provided below:

- SWMU 7 – Building 141 (Northwest Quadrant of the Siberia Area)
- SWMU 8 – Building 135 (along north wall)
- SWMU 9 – Building 115 (along south wall)
- SWMU 10 – Building 110, South (along west wall)
- SWMU 11 – Building 110, North (along west wall)
- SWMU 12 – Building 44 (along south wall)
- SWMU 13 – Building 35, South (along south wall)
- SWMU 14 – Building 25 (along northwest wall)

2.1.6. SWMU No. 15 - 17: Underground Waste Oil Storage Tanks

2.1.6.1. SWMU 15

SWMU 15 (UST 13) is the former location of a leaking 1,000-gallon underground waste oil storage tank located east of Building 15 (Figure 2-1). The UST was removed and replaced in 1995. A new tank and piping were installed once the WVA deemed the excavated pit to be satisfactorily clean based on the results of the soil, sediment, and groundwater/accumulated rainwater samples collected in the pit. The site was closed clean by the NYSDEC in February 1995. No further action is required for this SWMU.

2.1.6.2. SWMU 16

SWMU 16 (UST 23) is the former location of a 1,000-gallon waste oil storage tank in the west central portion of Building 35 (Figure 2-1). The UST was removed in 1994 and replaced with a new tank and piping. Composite soil samples that were collected from the excavation pit showed no reportable detections for VOCs and semi-volatile organic compounds (SVOCs). The excavated pit was backfilled with clean sand. No further action is required for this SWMU.

2.1.6.3. SWMU 17

SWMU 17 (UST 25) is a 5,000-gallon waste oil storage tank located east of Building 36 (Figure 2-1). The line and the tank were certified as being free of any leaks based upon two tightness tests conducted on January 10, 1995 and February 22, 1996. No further action is required for this SWMU.

2.1.7. SWMU No. 19: Outfall No. 003

Outfall 003 is the main WVA outfall to the Hudson River. This outfall includes the effluent from the industrial wastewater treatment plant (IWTP) that flows through Outfall 002. As shown on Figure 2-2, Outfall 003 is located east of Building 40. Prior to the construction of the IWTP in 1970 and the cyanide treatment plant in 1978, waste was discharged directly to the Hudson River via this outfall. This outfall is monitored in accordance with the WVA's SPDES permit. According to site personnel, exceedances of

permitted discharge limits for temperature, total suspended solids, and pH have been noted periodically in the past. However, these exceedances were considered “minor” and have never been repeated with any frequency. No leaks or breaks in the pipe have been documented and, according to the *RCRA Facility Assessment (RFA) Report, Watervliet Arsenal, Watervliet, New York* (RFA Report) (NYSDEC, 1992); it is unlikely that any traces of hazardous material remains in this outfall. No further action is required for this SWMU.

2.1.8. SWMU No. 20: Industrial Sewers

There are three types of waste lines that convey waste material to the on-site treatment plant in separate industrial sewers: acid rinse water, soluble waste oil, and cyanide rinse water. The acid and soluble sewers are constructed of both clay tile or plastic (polyethylene, polyvinyl chloride (PVC), and chlorinated polyvinyl chloride (CPVC)), depending on the section, and were installed in the early 1970s. Portions of the sewers have been upgraded since that time where necessary. The cyanide sewers were constructed of ductile iron pipe and were installed in the late 1970s. Use of these sewers was discontinued in 1994 when cyanide plating operations were phased out.

In 1992, Empire Soils Investigations, Inc. (Empire) conducted an investigation of leaks from the Manhole 34D of chromic acid line. The investigation revealed iron and manganese concentrations that exceeded NYSDEC Glass GA Standards and Guidance Values in the eight groundwater monitoring wells installed along the line (Empire, 1993a). During a video survey of the line conducted by Empire in 1992, twenty-three defects were noted. These defects were repaired and the line was re-sleeved in 1992 following the survey (Empire, 1993b).

In May 1993, during preventive maintenance, a number of potential leaking points were detected on the chromic acid rinse water line that conveys the waste to the onsite treatment plant (Building 36). The spill was reported to the NYSDEC, which resulted in the issuance of a consent order. Extensive line repair, soil removal, and groundwater extraction and monitoring were subsequently performed. All of the waste lines were upgraded in 1993 and 1994. Additional RFI activities, which included groundwater sampling, were initiated in 2000 to evaluate whether additional releases had occurred in the past. The contaminants of concern (COCs); RCRA-listed metals, polyaromatic hydrocarbons (PAHs), and cyanide, were not detected in the groundwater. Other than groundwater monitoring, no further action is required for this SWMU.

2.1.9. SWMU No. 21: Building 132 Incinerator

Building 132 was built in 1944 and is located at the western edge of the MMA near the gate leading to the Siberia Area (Figure 2-1). The incinerator was put on-line in 1945 and disposed of non-hazardous waste, primarily consisting of waste paper and office trash until 1975. Subsequently, Building 132 was used for the storage of pesticides and

insecticides. This practice was ended in the late mid-1990s when the WVA switched to the use of an outside contractor for pest and weed control services. The building is currently used for the storage of non-manufacturing recycling materials (i.e., paper) before shipment off-site. Based upon RFI groundwater and soil results that did not indicate the presence of contamination at concentrations greater than guidance levels, no further action is required for this SWMU.

2.1.10. SWMU No. 25: Erie Canal

The Erie Canal passed through the eastern portion of MMA (Figure 2-1), flowing in a north/south direction. The Canal was built between 1817 and 1824 and was filled in with dirt, brick, portions of the canal, and other unknown fill materials around 1940 during the World War II expansion at the WVA. When present, the canal provided transportation, power, and water for fire protection for the WVA until the canal was relocated to Waterford in 1922.

In 1993, WVA personnel observed machining coolant oil seeping into an excavation in the area of the waste oil line at Manhole 43, which is located within the area of the former Erie Canal. Approximately 15 to 30 yards of soil were excavated and a soil sample was collected, showing no evidence of contamination at concentrations greater than guidance values. Soil borings were completed in the former canal during the 1990 and 1997 hydrogeological investigations of the MMA. These samples indicated that the canal fill materials were predominantly silt and clay in nature. Analysis of a soil sample collected from 20 feet under pavement revealed petroleum and lead contamination at concentrations greater than guidance values. However, contamination was not encountered outside of the canal fill area or in groundwater samples downgradient of the canal. Based on these data, no further action is required for this SWMU.

2.1.11. SWMU No. 26: Building 35 Process Pit

Building 35, or the Heat Treat and Metal Processing Building, was constructed in 1918 along the southern property boundary of the MMA (Figure 2-1). In 1942 and during the mid to late 1970s (REARM project), Building 35 was extended and expanded into the current floor plan of 17 bays. Manufacturing activities conducted at Building 35 include chrome plating, cadmium-cyanide plating (discontinued in 1994), magnaflux testing, heat treatment, and cannon tube machining. The main waste types generated at Building 35 include water soluble cutting oil, combustible waste oil, metal chips, magnaflux testing oil, and process water from the chrome plating operations.

Four process pits were installed and used primarily for chrome plating of 155 mm guns, 8-inch guns, and equipment in Building 35. Today, two of the process pits are used for the chrome plating of cannon tubes. During the late 1980s, one of the original pits, the West pit, was converted to a furnace pit to be used for heat treatment of cannon tubes and is still currently being used for this purpose. In 1987, during the conversion of the

chrome plating pit to the furnace pit, petroleum, oils, and lubricants (POLs) was observed to be seeping through cracks in the concrete walls and accumulating in the furnace pit.

Various investigations have been conducted to assess the soil and water contamination from POLs due to the manufacturing processes at Building 35. In 1990 and 1991, Clough, Harbour and Associates (CHA) conducted and prepared a *Phase I Subsurface Contamination Investigation of the Chrome and Shrink Pit Areas in Buildings 35 and 135 of the Watervliet Arsenal, Albany* (Phase I Investigation) (CHA, 1991) report. As a result of the investigation, the petroleum in Building 35 was identified as containing compounds characteristic of kerosene and that the source of the oil found in the furnace pit was probably a result of POLs leaking from the machinery in Buildings 35 and 110. A passive recovery pump was installed in January 1999 to test the viability of Light Non-Aqueous Phase Liquid (LNAPL) (POLs) recovery. LNAPL recovery was found to be minimal with no effect on the presence or distribution of the LNAPL. Based upon groundwater and soil results that do not indicate the presence of contamination at concentrations greater than guidance levels, and that the distribution of LNAPL is stable, no further action, other than long-term groundwater monitoring, is required for this SWMU.

2.1.12. SWMU No. 27: Building 135 Process Pit

Building 135 was constructed in 1943 in the southwest corner of the MMA (Figure 2-1). The main shop floor area of the building is divided into five bays. A High Bay section is located at the south end of Building 135, rising approximately 50 feet above the rest of the building to facilitate lifting cannon tubes into and out of three pits: the Cold Works Pit, the Furnace Pit, and the Shrink Pit to WVA personnel. A Rotary Forge machine, considered the largest rotary forge in the world at the time, was installed in June 1975.

Manufacturing operations conducted at Building 135 include the delivery of raw steel billets; the forging of the billets into rough cannon tubes; the machining of the outside of the tubes; the lead plating and rifling of the inner bore; heat treatment, various quality control and strength tests on the partially completed cannon tubes prior to shipment to other buildings at the WVA. The main waste types generated at Building 135 include water soluble cutting oil, combustible waste oil, and metal chips from milling operations. Capacitors in the building that had contained polychlorinated biphenyls (PCBs) have been removed and replaced. Machines containing hydraulic oil with PCBs have been drained, flushed, and refilled with hydraulic oil containing less than 50 milligrams per liter (mg/l) PCBs.

The main focus of the Building 135 investigation was the Shrink Pit, which is located in the southeast corner of the building and is constructed of shale bedrock. The Shrink Pit houses three furnaces, an elevator, a metal stair case for access, a wet pit (commonly referred to as the “Blue Lagoon”) and a dry pit at the bottom. The Shrink Pit was used to

shrink a part of the gun tube, known as the hoop, onto the gun barrel. At its deepest point, the Shrink Pit is 100 feet deep and at its widest point is 51.5 by 40.5 feet wide (at the shop floor level). Drainage chases were installed around the perimeter wall of the Shrink Pit to collect groundwater for use in the shrinking process and were connected to the wet pit by a network of pipes. Groundwater that accumulates in the wet pit is pumped and discharged through Outfall 004 (Figure 2-2) to the storm sewer at the southern side of the building. This discharge is monitored by the NYSDEC under the WVA SPDES Permit.

Various investigations have been conducted to assess the soil and water contamination from POLs due to the manufacturing processes at Building 135. As mentioned previously, CHA conducted a Phase I investigation of the chrome and shrink pit areas in Buildings 35 and 135 in 1990 and 1991. As a result of the investigation, the petroleum in Building 135 was identified as containing compounds characteristic of refined petroleum lubricating oil and that the presence of LNAPL in the Blue Lagoon is most likely from POLs leaking from the machinery in Building 135. Based upon groundwater and soil results that did not indicate the presence of contamination at concentrations greater than guidance levels, and the lack of LNAPL in surrounding wells, no further action is required for this SWMU.

2.1.13. SMWU: Vapor Degreaser Units

Six vapor degreaser units were designated as part of the SWMU – Vapor Degreaser Units in the RFI Report. These vapor degreaser units, which were located in Buildings 20, 25, 40, 110, 120, and 130, were used for removing protective oil coatings from the surfaces of metal parts. The vapor degreaser units were exhausted to the atmosphere and were shut down periodically to remove accumulated sludges and oils. The units used chlorinated solvents, including PCE, TCE, and/or 1,1,1-TCA. Based on the results of the RFI, no further action is required for the vapor degreaser units at Buildings 20, 110, 120, and 130. The six buildings in which the vapor degreaser units are located are shown on Figure 2-1 and are discussed below:

- **Building 20:** The installation date of this vapor degreaser is unknown. The unit was idle from 1976 until its removal circa 1978.
- **Building 25:** See Sections 4 and 5.
- **Building 40:** See Sections 5 and 6.
- **Building 110:** The installation dates of the two degreasers known to have been present in this building are unknown. Both units were removed around 1976. According to WVA personnel, one of the units had been located in a section of the building called 110A, which was demolished in the early 1980s as part of Project REARM and is currently the location of the expanded Building 35.

- **Building 120:** The installation date of this vapor degreaser unit is unknown. The unit was removed around 1981. Approximately 250 feet south of the former location of this unit is a recovery well (RW-2), which was installed in 1993 as a result of an underground diesel fuel oil line leak. Groundwater samples collected during various monthly and quarterly sampling events from RW-2 have contained halogenated organics and other aromatics, including PCE and TCE at concentrations greater than guidance levels. Bedrock monitoring wells MW-8 and MW-64 are also located in the area of RW-2 and contain PCE and TCE at concentrations greater than guidance values. Based on the results of the RFI, the contamination at this location is not migrating and, therefore, no further action, other than long-term groundwater monitoring, is required for this area.
- **Building 130:** The installation date of this degreaser is unknown. The unit is presumed to have been removed in 1981.

2.1.14. Chip Handling Facility Areas

Two chip handling facilities, the Building 132 South Chip Handling Area and the Building 123 Chip Handling Area (area currently surrounded by Buildings 121, 122, and 123), were designated as SWMUs in the RFI Report and are shown on Figure 2-1. The exact dates of operation for both chip handling areas is unknown, but the chip handling area at Building 132 is believed to have been operational in the mid to late 1950s. The storage capacity of both areas is estimated to have been up to 80 tons, or approximately 40 cubic yards. Waste metal gun steel chips were generated and placed in these areas directly on the ground. Various cutting oils coated the chips, which according to WVA, “dripped off or washed off during storm events.”

Various investigations have been conducted in these areas to assess the soil and water contamination due to the chip handling facility activities, as well as the environmental effects of an 8,000-gallon fuel oil release near Building 121. In November 1992, Lockwood Greene Engineers, Inc. (LGE) completed a Preliminary Assessment Screening Report and, in June 1993, Huntingdon-Empire Soils (HES) completed a soils characterization report for the Building 132 South Chip Handling Facility. Both reports confirmed that soils in this area were contaminated with total petroleum hydrocarbons. As a result of a natural gas line being installed to the WVA’s boiler plant (January to March 1994), the contaminated soils were excavated, removed, and disposed of at a nearby landfill.

No intrusive investigations had been completed for the SWMU in the Building 123 Chip Handling Area. However, piezometers and test holes were completed as part of a study conducted by William F. Cosulich Associates, P.C. (WFCA) in 1978. According to the Oil Pollution Source Elimination Study (WFCA, 1980), the Building 123 Chip Handling Facility was operated between the late 1950s and 1960s and then up until approximately 1976 was used “as a wash rack area for cleaning oil from metal.” The processes occurring in Building 121, the diesel oil spill (8,000-gallon release) at Building 116, and

the Building 123 Chip Handling Facility, were all listed as sources of groundwater and soil contamination in this area. As a result of the presence of LNAPL observed in wells, piezometers, and test pits installed in this area, two interceptor trenches were installed in 1975 and 1976 to limit migration of oil from the source area. The one trench is located on the north side of Building 121 and the other trench was installed alongside the railroad track that runs northwest of Building 121. Details in regards to the installation of the interceptor trench and the removal of oil impacted soil to an off-site disposal site were included in the Update of the Initial Installation Assessment of Watervliet Arsenal report prepared by Environmental Science and Engineering, Inc. (ESE) in July 1987 (ESE, 1987). No further actions are required for this SWMU.

2.1.15. Chrome Plating Pit Areas

The basic function of the Chrome Plating Pits is to collect spillage and drainage from the chromium plating, anodizing, cadmium cyanide (use of this compound was discontinued in 1994), and manganese phosphate lines which contain caustic cleaners, electro-polishing, rinse water, and plating/coating solutions. The sump liquid and cyanide spillage and drainage is separately pumped and delivered to the industrial waste treatment plant. Waste placed into these pits include chromic acid and other plating fluids, such as caustic cleaners; sulfuric and phosphoric acids; cadmium, nickel, copper, manganese phosphate plating/coating solutions and rinse waters. The Chrome Plating Areas are located in Building 35 and, formerly, in Building 110, which are shown on Figure 2-1 and discussed separately below. No further actions are required for this SWMU.

- **Building 35 Minor Plating Area:** The plating area operations began in 1983 and are on-going. This pit consists of four adjacent plating/coating lines in a 135 x 56 foot area in the east-central side of Building 35. Many of the processing tanks in this area are approximately 700 gallons, but range in size up to 2,200 gallons. In July 1993, Empire Soils collected groundwater samples from monitoring wells 100 to 200 feet downgradient of the sump area, which showed that no RCRA-listed metals other than lead exceeded the applicable guidance values (Empire, 1993b).
- **Building 35 Major Plating Area:** This plating area consists of four adjacent pits in the southwest corner of Building 35 and are identified from west to east as the 120 mm cannon pit, the 155 mm furnace pit, the 8-inch cannon pit, and the new medium tube (NMT) pit. The 155 mm furnace pit operated from 1952 to 1987 when the pit was converted to an electric oven heat treatment facility. The 8-inch cannon pit, NMT pit, and 120 mm cannon pit began operating in 1976, 1980, and 1987, respectively. The 8-inch pit and NMT pit have been abandoned and are no longer used. The chrome plating tanks have a capacity of 12,760 gallons of fluid, while the associated tanks, which are used for rinsing, electropolishing, and cleaning, hold approximately 2,800 gallons of fluid.
- **Building 110 LC Plating Area:** The liquid chrome (LC) plating area was a pit divided equally into two sections, a shallow (approximately 40 feet deep) section and a deep (approximately 70 feet deep) section, with small individual holding tanks. The

plating area was located in the center of Building 110. The shallow section was in operation since the 1940s and was renovated from 1982 to 1984. Use of both sections of the pit was discontinued in 1991 and the pit was permanently abandoned in 2009 by backfilling with flowable fill.

2.1.16. Chrome Plating Scrubbers

Air exhaust scrubbers are used to remove contaminants entrained in the exhaust air from chrome plating operations, prior to discharge to the atmosphere. The scrubbers are located at Buildings 35 and 114 (used for laboratory testing only). The water used to remove the contaminants from the air stream is automatically discharged to the wastewater treatment plant. No further actions are required for this SWMU.

2.2. Areas of Concern

The areas of concern (AOCs) identified in the MMA are summarized below and in Table 2-2. All of the AOCs are categorized within the Vapor Degreaser Units SWMU.

2.2.1. Groundwater

Groundwater samples were collected during the RFI, the Long-Term Monitoring (LTM) program, and the various CMS studies. The nature of the groundwater contamination in the MMA is primarily related to the presence of CVOCs, which were used prior to 1982 in vapor degreasing operations. Groundwater containing CVOCs at concentrations greater than guidance values is found in the following general areas:

- Building 40
- Building 25
- Building 114 area

2.2.1.1. Building 25

Groundwater contamination is primarily located east and southeast of Building 25, coincident with the groundwater flow direction in this area of the MMA. The contamination primarily consists of PCE, TCE, vinyl chloride (VC), 1,1-dichloroethane (1,1-DCA), and 1,1,1-TCA, which exceed the corresponding NYSDEC Class GA Standards in the overburden, weathered bedrock, and bedrock groundwater.

Based on the results of the RFI, the horizontal extent of groundwater CVOC contamination is limited to an approximately 0.4-acre area in the vicinity of well cluster 86EM-SP-1B (SP-1B)/WVA-AW-MW-47 (MW-47) to the south, and by the eastern edge of the former Erie Canal to the east (Figure 2-3). This area is adjacent to, and downgradient from, the location of a vapor degreaser formerly located in the southeast corner of Building 25. The highest concentrations of chlorinated VOCs detected in the overburden were at well WVA-AW-25-MW-3 (MW-3) and in the bedrock were at well

WVA-AW-25-MW-2 (MW-2) (Figure 2-3). Based on downgradient monitoring, the CVOCs are not migrating beyond the former Erie Canal or the WVA property boundary.

2.2.1.2. Building 40

Groundwater contamination at Building 40 primarily consists of PCE and cis-1,2-dichloroethene (cDCE), with a lesser percentage of TCE and VC. All of these contaminants are found in the bedrock groundwater. Overburden groundwater is not impacted. Based on the results of the RFI, LTM program, and the various CMS studies, the horizontal extent of bedrock groundwater contamination is limited to the area that extends southeast from monitoring well WVA-AW-MW-79 (MW-79) and WVA-AW-MW-88 (MW-88) (west of Building 40) to the eastern site boundary and, presumably, beyond the site boundary to the Hudson River (Figure 2-4). As discussed herein, the majority of the CVOC mass is entrained in the bedrock matrix. The exact source of the CVOCs in the groundwater at Building 40 is not known. However, there are no known continuing surface sources of CVOCs in the groundwater in the Building 40 area.

2.2.2. Soil Vapor

2.2.2.1. MMA

In accordance with the directive by the NYSDEC and the New York State Department of Health (NYSDOH), the WVA performed vapor intrusion investigations within, and adjacent to, the MMA from 2007 through 2008. The purpose of the investigation was to assess whether CVOCs were present in the sub-slab soil vapor beneath, and the indoor air within, buildings located in the MMA, including those that once contained degreasing operations, as well as three off-site private residences along the southeastern WVA property boundary. The evaluation also assessed whether soil vapor at the WVA southern property boundary contained CVOCs. A total of 25 buildings in the MMA were sampled during at least one of the two investigation phases. Based on the results of the investigations, no further action is required at the off-site residences, the WVA property boundary, and at Buildings 9, 18, 19, 23, 24, 35, 38, 44, 108, 110, 112, 115, 116, 123, 124, and 126. Corrective measures were found to be required for Buildings 20, 21, 22, 25, 114, 120, 121, and 130 due to the presence of CVOCs in soil vapor and/or indoor air at concentrations greater than guidance values (Figure 2-5).

2.2.2.2. Building 40

Due to the presence of CVOCs in the bedrock groundwater to the east of Building 40, the extent and concentration of VOCs in the indoor air within and the soil gas beneath Building 40 was investigated in a separate investigation. The investigation found that CVOCs were present in the soil vapor and indoor at concentrations greater than guidance values and corrective measures were required.

3. Corrective Action Objectives and Technology Screening

3.1. Groundwater Corrective Action Objectives

3.1.1. Building 25

The Corrective Action Objectives (CAOs) for groundwater in the Building 25 area of the MMA are the NYSDEC Class GA groundwater standards and/or guidance values, which are presented in Table 3-1. Compliance with the groundwater CAOs is measured at the monitoring wells immediately downgradient (east) of Building 25.

3.1.2. Building 40

The CAOs for groundwater in the Building 40 area of the MMA are the NYSDEC Class GA groundwater standards and/or guidance values listed in Table 3-1 or the approved alternate concentration limits (ACLs). However, given the likely presence of DNAPL in the fractured bedrock at the site, and the presence of CVOCs in the bedrock matrix, it is recognized that the achievement of the CAO may take a very long time or may not be achievable using currently available technologies.

3.2. Soil Vapor Intrusion Corrective Action Objectives

The CAOs for soil vapor and indoor air are the action levels listed in the *Guidance for Evaluating Soil Vapor Intrusion in the State of New York* (NYSDOH 2006).

3.3. Groundwater Technology Screening Summary

Various remedial technologies were evaluated to determine the potential of achieving site remedial objectives using both conventional and innovative remedial alternatives. The following programs/information resources were utilized to identify and review technologies for remediation of CVOCs in groundwater that may be potentially applicable to the Building 40 and Building 25 groundwater:

- United States Environmental Protection Agency (USEPA) Superfund Technology Innovation Program (TIP) (formerly the Technology Innovation Office (TIO));
- USEPA Cleanup Information (CLU-IN) Website (www.clu-in.org);
- Federal Remediation Technologies Roundtable;
- Environmental Security Technology Certification Program (ESTCP);
- Strategic Environmental Research and Development Program (SERDP);
- Interstate Technology and Regulatory Council (ITRC);

- Air Force Center for Engineering and the Environment (AFCEE);
- Naval Facilities Engineering Command (NAVFAC);
- National Groundwater Association – Groundwater On-line Database;
- University of New Hampshire Bedrock Bioremediation Center; and
- U.S. Geological Survey (USGS) Toxic Substances Hydrology Program.

In addition, the following publications were reviewed:

- Federal Remediation Technologies Roundtable. 2009. *Treatment Technologies Screening Matrix*.
- Interstate Technology Regulatory Council (ITRC). 2008. *In Situ Bioremediation of Chlorinated Ethene DNAPL Source Zones*. June 2008.
- LaChance, John (TerraTherm) and Pierre Lacombe (USGS). 2009. *Thermal Treatment of DNAPL in Fractured Bedrock Using Thermal Conduction Heating*. Presentation for 2009 Fractured Rock Technology Seminar and Guided Site Tour, Naval Air Warfare Center, West Trenton, New Jersey. June 2009.
- McDade, James M., Travis McGuire, Charles Newell. 2005. *Analysis of DNAPL Source-Depletion Costs at 36 Field Sites*. Spring 2005.
- National Groundwater Association. *Fractured Rock: State of the Science and Measuring Success in Remediation*. September 2005.
- National Research Council (NRC). 2005. *Contaminants in the Subsurface, Source Zone Assessment and Remediation*.
- Sale, Tom, Charles Newell, Hans Stroo, Robert Hinchee, and Paul Johnson (ESTCP). 2008. *Frequently Asked Questions Regarding Management of Chlorinated Solvents in Soils and Groundwater*. July 2008.
- Strategic Environmental Research and Development Program. 2007. *Project Fact Sheet: A Comparison of Pump-and-Treat Natural Attenuation, and Enhanced Biodegradation to Remediate Chlorinated Ethene-Contaminated Fractured Rock Aquifers*, Naval Air Warfare Center, West Trenton, New Jersey. October 2007.
- United States Environmental Protection Agency. 2005. *Steam Enhanced Remediation Research for DNAPL in Fractured Rock, Loring Air Force Base, Limestone, Maine*. National Risk Management Research Laboratory, Cincinnati, Ohio. August 2005.

The technology-specific information is presented in the following subsections. The applications of potential remedial alternatives were screened according to geologic and hydrogeologic conditions, the nature of contamination, engineering requirements, and implementability. Final selected technologies were based on the ability to achieve the CAOs, the physical constraints of the impacted areas, and the limitations imposed by operations at the MMA.

3.3.1. Bedrock Matrix and Groundwater

Corrective measures technologies were chosen for groundwater that could potentially meet the CAOs. Some of the corrective measures technologies are general in nature, describing broad categories of potential remedies, while other technologies are specific remedial options for the site. The following corrective measures technologies were retained for consideration for the Building 25 and Building 40 bedrock matrix and/or groundwater.

1. Monitored Natural Attenuation (MNA);
2. Containment;
3. In-Situ Treatment;
4. In-Situ Thermal Remediation (ISTR); and
5. No Action.

3.3.2. Monitored Natural Attenuation (MNA)

Natural attenuation may be considered for remediation of contaminants in groundwater and saturated soils if site-specific factors support its use. The factors include:

- Protection of potential receptors during attenuation;
- Favorable geological and geochemical conditions;
- Documented reduction of degradable contaminant mass in a reasonable time frame in the surface and subsurface soils;
- Confirmation in microcosm studies of contaminant cleanup; and
- For the persistent or conserved contaminants, ensured containment during and after natural attenuation.

Target contaminants for natural attenuation are VOCs, SVOCs, and fuel hydrocarbons. Fuel and halogenated VOCs (chlorinated solvents) are so far the most commonly evaluated for natural attenuation. Pesticides also can be allowed to naturally attenuate, but the process may be less effective and may be applicable to only some compounds within the group.

Factors that may limit the applicability and effectiveness of the process include:

- Extensive site characterization with modeling and long-term monitoring may be more costly than active remediation.
- Toxicity of degradation and transformation products may exceed that of the original contaminants.
- Risks occur at sites where geological characteristics such as fractured bedrock make contaminant assessment and hydraulic control difficult.

- Contaminants may migrate past site boundary before they are fully degraded or transformed.
- The source must be removed so there is no continuous release to groundwater.

MNA would involve the degradation of CVOCs in the overburden and bedrock groundwater by naturally occurring processes (i.e. biodegradation). Such degradation is monitored over time under a long-term monitoring program at both Building 25 and Building 40. The presence of PCE breakdown products, TCE, cDCE, and VC indicates natural attenuation is ongoing in the overburden and bedrock groundwater at Building 25 and in the bedrock groundwater at Building 40. In addition, the presence of the organism *dehalococcoides ethegenes* (DHE), which is capable of completely degrading CVOCs, has been confirmed in bedrock groundwater samples collected from the Building 25 and Building 40 areas.

Even though natural attenuation of CVOCs in groundwater at Building 25 and Building 40 is occurring, by itself, the process has not significantly reduced the concentration of CVOCs in the groundwater, although it has likely limited its lateral extent. However, through bedrock matrix diffusion, the migration of CVOCs in the groundwater has been attenuated. Even though the natural attenuation processes have served to reduce the mass and extent of CVOCs in the overburden and bedrock groundwater and could potentially result in the achievement of CAOs, the rate at which they currently occur is slow and would not result in a measurable decrease in contaminant mass or groundwater concentration in the near future. Given this, MNA, by itself, was eliminated from further consideration. MNA coupled with a more effective source treatment technology, however, was retained for further consideration.

3.3.3. Containment

Containment includes in-situ and ex-situ treatments, such as extraction and barrier technology (i.e., slurry wall/vertical barrier and permeable barrier walls) that would be employed to prevent contaminants from entering adjacent properties and essentially “contain” the contaminant plume. The most widely used containment method is groundwater extraction and treatment. Groundwater extraction and treatment technologies, commonly referred to as a “pump and treat” systems, have been widely used for two decades, growing in prominence in the early to mid-1980s.

Target contaminants for containment via groundwater extraction and treatment, are VOCs, SVOCs, fuel hydrocarbons, unexploded ordnance (UXO) (i.e., explosive compounds) and dissolved metals. Fuel and halogenated VOCs (chlorinated solvents) are the most commonly evaluated contaminants for groundwater extraction and treatment remedial systems.

Factors that may limit the applicability and effectiveness of the process include:

- Site geology and contaminant characteristics/distribution.
- Treatment may take a very long time (i.e., greater than 100 years) to meet the NYSDEC Class GA groundwater standards and/or guidance values.
- Desorption and/or back-diffusion of contaminants from the soil or bedrock matrix once groundwater extraction ceases and groundwater level rises creating a potential increase, essentially a rebound, in contaminant concentrations in the groundwater.
- Combination with complementary technologies (e.g., bioremediation, air sparging, dual phase extraction, and soil flushing) may be required to lower contaminant concentrations.

Groundwater extraction would involve the use of one or more wells to intercept and remove groundwater containing CVOCs from the subsurface. Groundwater extracted from the subsurface would then be treated at the surface and discharged under the appropriate discharge permit. Groundwater extraction would be accompanied by long-term groundwater monitoring to evaluate the degree to which CVOCs are removed from the subsurface and to evaluate the rebound in CVOC concentrations after the cessation of pumping.

Similar to MNA, the use of containment technologies, such as groundwater extraction and treatment, by itself, would result in a reduction in groundwater CVOC concentrations at the property boundary and prevent migration of the groundwater plume to adjacent properties, but would do little to reduce CVOC mass in the shale bedrock matrix. As such, groundwater concentrations would be expected to rebound to near their pre-remediation concentrations upon shut down of the containment remedy since CVOC source concentrations in the shale bedrock aquifer would be relatively unaffected by extraction of the groundwater.

A USEPA study of 28 sites at which groundwater containment remedies have been implemented found that, while 21 of 25 sites have met plume containment goals, only two of 28 sites have met their aquifer restoration goals (USEPA 1999). In fact, the study stated that the “EPA has concluded that one of the most effective means of remediating a site at which contaminated groundwater is present is to remove, or at least isolate, the source material from the groundwater.” These data indicate that, while containment remedies are viable remedies to eliminate potential exposure pathways, they are not effective source treatment technologies and are not suitable at sites where the source of the contamination has not been remedied. Therefore, the use of containment technologies (i.e. groundwater extraction and treatment) for Buildings 25 and 40 bedrock groundwater was eliminated from consideration.

3.3.3.1. In-Situ Treatment – Enhanced Bioremediation, Hydrogen Release Compound

In-situ treatments involve the addition of amendments to destroy or promote the enhanced degradation of, CVOCs. These technologies typically require long-term groundwater monitoring to verify the degradation of the CVOCs and to evaluate when or if additional injections are required. Enhanced bioremediation is one typical in-situ treatment in which indigenous or inoculated microorganisms (e.g., fungi, bacteria, and other microbes) degrade (metabolize) organic contaminants found in groundwater, converting them to innocuous end products. Nutrients (e.g., carbon, oxygen, nitrates) or other amendments may be used to promote and accelerate the ongoing bioremediation and contaminant desorption from subsurface materials.

Bioremediation can take place under aerobic or anaerobic conditions. In the presence of sufficient oxygen (aerobic conditions), microorganisms use atmospheric oxygen to function and can convert many organic contaminants to carbon dioxide, water, and microbial cell mass. In the absence of oxygen (anaerobic conditions), the organic contaminants are ultimately metabolized to methane, limited amounts of carbon dioxide, and trace amounts of hydrogen gas by microorganisms. Sometimes contaminants may be degraded to intermediate or final products that may be less, equally, or more hazardous than the original contaminant. For example, TCE anaerobically biodegrades to the more toxic VC. VC can be degraded further if the proper conditions are created.

There are four major processes that enhance bioremediation; nutrient injection, oxygen enhancement with hydrogen peroxide, nitrate enhancement, and bio-augmentation. At the MMA, nutrient injection was considered as a possible remedial technology for Building 25, specifically, the injection of hydrogen release compound (HRC[®]) into the subsurface. Hydrogen release compound is an environmentally safe polylactate ester that supplies additional carbon to the subsurface to be used by anaerobic microorganisms. These organisms release hydrogen and accelerate reductive dechlorination reactions (substitute carbon with hydrogen in chlorinated VOCs) that convert CVOCs into ultimately ethanes or ethenes (i.e., PCE → TCE → cDCE → VC → ethene).

When HRC[®] becomes hydrated, lactic acid is slowly released to the subsurface, which begins various biochemical reactions. In anaerobic environments, microorganisms, such as acetogens, metabolize the lactic acid provided by the HRC[®], producing low concentrations of dissolved hydrogen. The hydrogen is then used by other subsurface organisms (reductive dehalogenators) to strip CVOCs of their chlorine atoms and allow for biological degradation. Nutrient injection can be injected either in the source area to remove contaminant mass or as a barrier to prevent ongoing migration of a contaminant plume.

Bioremediation techniques have been successfully used to remediate soils, sludges, and groundwater contaminated with petroleum hydrocarbons, solvents, pesticides, wood

preservatives, and other organic chemicals. Bench- and pilot-scale studies have demonstrated the effectiveness of anaerobic and aerobic microbial degradation of halogenated and non-halogenated organic compounds in groundwater. Bioremediation is especially effective for remediating low level residual contamination in conjunction with source removal. While bioremediation (nor any other remediation technology) cannot degrade inorganic contaminants, bioremediation can be used to change the valence state of inorganics and cause adsorption, immobilization onto soil particulates, precipitation, uptake, accumulation, and concentration of inorganics in micro or macroorganisms.

Factors that may limit the applicability and effectiveness of the process include:

- Preferential colonization by microbes may occur causing clogging of nutrient injection wells, limiting adequate contamination and microorganism contact throughout the contaminant zone.
- Fluctuations in the water table may impact the effectiveness of this technology in the “smear zone.”
- Preferential flow paths may severely decrease contact between injected fluids and contaminants throughout the contaminated zones. Engineered controls should be implemented for clay, highly layered, or heterogenous subsurface environments because of oxygen (or other electron acceptor) transfer limitations.
- High concentrations of heavy metals, highly chlorinated compounds, long chain hydrocarbons, or inorganic salts are likely to be toxic to microorganisms.
- Bioremediation is not preferred for soils with low permeabilities (i.e., fine clays).
- Bioremediation slows at low temperatures.
- Contaminant mobility may increase with the use of a water-based solution through soil, requiring the use of another remediation technology to remove contaminants from the groundwater or prevent expansion of the contaminant plume.
- Under anaerobic conditions, contaminants may be degraded to a product that is more hazardous than the original contaminant.

However, many of these factors can be controlled with a properly designed remediation program.

Enhanced biodegradation would accelerate the degradation of the CVOCs in the overburden and bedrock groundwater, however, similar to MNA, many of the enhanced biodegradation technologies are applicable only to the CVOCs present in the groundwater. The use of most enhanced bioremediation technologies create a greater reverse diffusion gradient by which CVOCs in the overburden and bedrock matrix would be drawn into the groundwater more quickly. However, the rate at which this would occur may not result in a measurable decrease in overall contaminant mass in the near

future (i.e., greater than 100 years). Overall, the advantages of using HRC[®] versus other carbon sources and enhanced bioremediation technologies include the following:

- **Long Reaction Time:** The compound's patented time release feature allows a one-time application to treat an entire site, thus it may not have to be reapplied repeatedly as with other carbon sources, such as molasses or common sugar solutions.
- **Viscous Solid with Low Solubility:** HRC[®] stays in place where it is injected and generates hydrogen.
- **Desorption of Chlorinated VOCs:** The continuous hydrogen source provided by HRC[®] can reduce dissolved phase chlorinated VOC concentrations by creating a larger concentration gradient, which in turn facilitates desorption of CVOCs from the soil or rock matrix. Thus, by applying HRC[®] to treat the source and increase the rate of chlorinated VOC desorption, treatment time may be reduced without increasing contaminant concentration in groundwater.
- **Low Capital Cost:** HRC[®] application required low capital costs as it is relatively inexpensive and is generally applied to the subsurface through push-point type applications.
- **Low Operation and Maintenance Cost:** Unlike actively engineered systems, the use of HRC[®] requires no continuous mechanical operation, therefore operating and maintenance costs are eliminated.
- **Minimal Site Disturbance:** Treatment with HRC[®] is in-situ; thus, above ground disturbance is minimized.
- **Rapid Treatment:** By supplying a consistent low level of hydrogen over approximately one year's time, the dechlorination process is stimulated to increase in the subsurface by orders of magnitude. This results in a very rapid removal of the CVOC contamination when compared to natural attenuation approaches.

Based upon the longevity, implementability, and lower cost of injecting HRC[®] in the subsurface, use of HRC[®], accompanied by long-term MNA was selected as the preferred technology for the treatment of CVOCs in the Building 25 groundwater.

3.3.3.2. In-Situ Treatment – Chemical Oxidation, Fenton's Reagent

The in-situ chemical oxidation (ISCO) treatments involve the delivery and distribution of oxidants and other amendments (e.g., catalysts) into the subsurface to chemically transform organic contaminants of concern into innocuous end products such as carbon dioxide (CO₂), water, and inorganic compounds which are more stable, less mobile, and/or inert. The primary advantages of ISCO technologies are their relatively lower capital cost and shorter treatment times than extraction technologies. Since the reaction is near immediate, treatment is also far more rapid than biological techniques.

Hydrogen peroxide-based Fenton's reagent is a well documented and effective in-situ chemical oxidation treatment. Fenton's reagent is a solution that is formed on-site by

mixing hydrogen peroxide (H_2O_2) and a ferrous iron (Fe^{+2}) catalyst together to produce hydroxyl radicals ($OH\bullet$), which is a very powerful nonspecific oxidizing agent, second only to fluorine in oxidizing power. Because hydrogen peroxide degrades rapidly in the environment, excess oxidant in the subsurface does not represent an environmental impact. However, the complete oxidation of contaminants requires sufficient time so that residual compounds are completely removed from the contaminant stream. Therefore, Fenton's reagent is most effective for dissolved phase contamination in groundwater.

Many reactions can occur during the oxidation of a contaminant. A contaminant, such as a halogenated organic compound (i.e., TCE), will react with hydrogen peroxide and ferrous iron (as a catalyst) to ideally produce carbon dioxide, water, hydrogen, and chloride ions, which are non-toxic. The hydrogen peroxide, catalyst, buffering solution (if needed), and water, which is used for dilution (solution is typically 5 to 20 percent hydrogen peroxide concentration), can be applied to saturated and unsaturated soil and bedrock by gravity feed or pressure through preexisting or newly installed monitoring wells and injection points screened at the targeted zone for the most effective remediation of the groundwater plume.

Fenton's reagent can be used to treat a wide variety of organic and inorganic contaminants in soil and groundwater, including chlorinated solvents, petroleum hydrocarbons, PAHs, SVOCs, pesticides, PCBs, phenolics, wood preservatives, and ordnance compounds.

When DNAPLs are oxidized within the soil interface, organic contaminants become desorbed from the soil, or essentially enter the aqueous phase. Oxidation continues to oxidize the contaminants within the interstitial groundwater. As a result of the oxidation process, aerobic biodegradation of contaminants can benefit from the presence of oxygen released during the decomposition of hydrogen peroxide.

Factors that may limit the applicability and effectiveness of the process include:

- Subsurface heterogeneity can cause uneven distribution of oxidants. Once injected into the subsurface, there is no control over the movement of the oxidant.
- Because the cost of ISCO injections is related to the depth and quantity of DNAPL, the number and pattern of injection and extraction wells (if necessary) and monitoring wells must be designed to ensure maximum coverage of the treatment zone.
- ISCO with Fenton's reagent often requires more than one application of oxidant to address rebound effects. Subsequent injection events may be hindered by the decrease in porosity of the subsurface due to the formation of metal oxide precipitates.
- With ISCO systems using Fenton's reagent, reduction of pH to levels between three and six standard units (S.U.) is required because at natural groundwater pH conditions

(six to seven S.U.), a ferrous catalyst will precipitate as its oxidized form (ferric iron), resulting in localized hydroxyl radical generation and a limited area treated by the reagent.

- Hydroxyl radicals generated can react with common inorganic species in groundwater, such as carbonate and bicarbonate, which can result in less hydroxyl radicals available to break down the contaminants. However, carbonate may act as a pH buffer and prevent the reduction in pH level necessary for the Fenton's reagent reaction to occur.
- Large quantities of Fenton's reagent are required for treatment of DNAPLs. Typically, Fenton's reagent is not applicable at sites where more than six inches of contaminant free product is present.
- Cost of using Fenton's reagent can increase in the presence of native organic matter which exerts a larger demand for oxidants.
- Lack of proper site characterization, calculation of injection variables (i.e., injection pressure and reagent concentration), and/or monitoring of injection operations may result in adverse effects, such as the development of carbon dioxide and/or oxygen off-gas, which can mobilize vapors and contaminants within the subsurface that may cause explosions in an inappropriate environment.

Rapid reaction times and high destruction efficiencies can be achieved with hydrogen peroxide, resulting in significantly reducing concentration at source areas and reducing remediation costs over the life of the project. Based on the stoichiometry of the oxidation of TCE by hydrogen peroxide, it would take 0.8 pounds of oxidant to fully oxidize one pound of TCE.

Hydrogen peroxide can be used to treat DNAPL sources within both the saturated and unsaturated zones of soil and bedrock. Since the Fenton's reagent is applied in-situ directly to the contaminant, the reagent should not cause vertical movement of the contaminant, which is often a concern with other remediation technologies. Typically, extensive geophysical logging, packer testing, and discrete sampling are conducted to evaluate fracturing and hydraulic properties of the soil and bedrock to appropriately design the full scale injection treatment. The use of Fenton's reagent in fractured bedrock has been limited, but when used during field studies the oxidant has been successful. However, the use of fast-reacting chemical oxidants, such as Fenton's reagent, at the MMA, would have an effect similar to that of groundwater extraction, in that the CVOCs in the bedrock fractures and overburden would be removed, but there would be little treatment of the CVOC mass in the shale bedrock matrix source. Given this, the use of Fenton's reagent was eliminated from consideration.

3.3.3.3. In-Situ Treatment – Chemical Oxidation, Potassium and Sodium Permanganate

Another well-documented and effective in-situ chemical oxidation treatment is to inject potassium and/or sodium permanganate into the area of concern. Potassium

permanganate is a solid and is typically mixed with water to create a 2 to 5 percent solution on-site, while sodium permanganate is a 40 percent solution that is sent to the site containerized in a 55-gallon drum. Typical concentrations for sodium permanganate solutions injected into the subsurface are 5 to 20 percent, depending on the site characteristics. Potassium and sodium permanganate have the same oxidative capabilities, but sodium permanganate is 10 times more soluble than potassium permanganate and is more concentrated. Permanganate is a weaker oxidizer than hydroxyl radicals, but is more stable in the subsurface and has been shown to remain active in the subsurface for months after injection.

Potassium and sodium permanganate can completely oxidize certain chlorinated hydrocarbons in-situ, including those commonly found at DNAPL sites (e.g., PCE and TCE) without the production of toxic daughter products. Hazardous intermediate compounds may be formed due to incomplete oxidation caused by insufficient quantity of either oxidant or catalyst, the presence of interfering compounds (e.g., natural organic-rich media, iron, manganese, magnesium, and calcium) that consume the reagents, and/or inadequate mixing or contact time between contaminant and oxidizing agent. The primary products of the reaction between permanganate and PCE and/or TCE are hydrochloric acid (HCl), CO₂, and manganese dioxide (MnO₂). These products are generally not considered harmful in the groundwater environment. However, it is important to understand the fate of the primary by-products in order to minimize adverse impacts to the treatment zone.

- CO₂ – Carbon dioxide will combine with water to form the carbonate series and lower the pH of the groundwater.
- HCl – Hydrochloric acid is highly reactive and unpredictable, and is typically neutralized in the groundwater environments.
- MnO₂ – Manganese dioxide will precipitate out of solution and coat soil and bedrock pore spaces and bedrock fractures. The buildup of manganese dioxide, and other manganese oxides, may reduce aquifer permeability over time, thereby hindering delivery of oxidant to contaminated zones.

Chemical oxidation, via potassium and sodium permanganate, occurs at both the soil interface and free-phase interface (for NAPL situations) and within the interstitial pore spaces in saturated subsurface (for dissolved compounds). Organic compounds that contain carbon-carbon double bonds (alkenes) are more readily oxidized by permanganate than compounds having single carbon-carbon bonds (alkanes). Thus, permanganate is more effective at remediating chlorinated VOCs containing PCE and/or TCE rather than 1,1,1-TCA.

Factors that may limit the applicability and effectiveness of the process include:

- Subsurface heterogeneity can cause uneven distribution of oxidants. Once injected into the subsurface, there is no control over the movement of the oxidant.
- Because the cost of ISCO injections is related to the depth and quantity of DNAPL, the number and pattern of injection and extraction wells (if necessary) and monitoring wells must be designed to ensure maximum coverage of the treatment zone.
- ISCO with permanganate often requires more than one application of oxidant to address rebound effects. Subsequent injection events may be hindered by the decrease in porosity of the subsurface due to the formation of metal oxide precipitates.
- The potential to alter subsurface biogeochemistry and locally mobilize co-contaminants (e.g., redox sensitive metals such as chromium).
- The process may not be cost-effective for high contaminant concentrations in a large surface area because of the large amounts of oxidizing agent required.
- Incomplete oxidation or formation of toxic intermediate contaminants may occur.
- Large quantities of permanganate are required for treatment of DNAPLs.

Rapid reaction times and high destruction efficiencies can be achieved with potassium and sodium permanganate, resulting in significantly reducing concentration at source areas and reducing remediation costs over the life of the project.

Since potassium and sodium permanganate are relatively stable and can remain active in the subsurface for months after injection, they can diffuse into media with low permeabilities (i.e., clay and porous rock) over time, further enhancing oxidant/contaminant contact and destroying CVOC mass in the matrix. Application of excess potassium and sodium permanganate can allow for diffusion of permanganate into the matrix at the same time as contamination is diffusing out of the matrix (i.e., the reactants will be moving toward each other) adding to the treatment of the CVOC mass in the rock matrix. Since the permanganate is applied in-situ directly to the contaminant, the oxidant should not cause vertical movement of the contaminant, which is often a concern with other remediation technologies. Pilot studies utilizing permanganate in fractured bedrock have been limited due to the inherent complications of injecting into fractured bedrock. However, based upon the stability and longevity of permanganate in the subsurface, use of permanganate, accompanied by long-term MNA was selected as the preferred technology for the CVOCs in the Building 40 groundwater.

3.3.3.4. In-Situ Treatment – Iron Injection, Zero-Valent Iron and Nanoscale Zero-Valent Iron

Zero-valent iron (ZVI) has been used and well studied in permeable reactive barriers (PRBs) for groundwater treatment for almost 20 years. PRBs were not considered as a viable remediation technology for the groundwater at Building 25 and Building 40 because a majority of the CVOC contamination is located in the bedrock. For a PRB to be successful, the contact between the barrier and the contaminant is critical for

remediation. Because the groundwater flow in bedrock fractures is unpredictable, contact with the groundwater plume may be limited and an unknown volume of the plume may pass by the barrier, resulting in some of the contaminant not being treated. Thus, trenching and constructing a PRB would not be cost effective or the best remedy for the treatment of this particular groundwater contaminant plume.

ZVI and nanoscale zero-valent iron (NZVI) colloids can be utilized in the Building 25 and Building 40 overburden areas, but as injected materials, not as a PRB. ZVI and NZVI are injected in the source area or down gradient of the flow path of a contaminant plume, allowing the water portion of the source area or plume to passively move through the injected material while the contaminants react with the colloids within the slurry. Once the contaminants come in contact with the ZVI or NZVI slurry, the reactions that occur break the contaminant down into harmless products or immobilize the contaminants by precipitation or sorption. Based on size, NZVI colloids react with the contaminants and flow with the groundwater, but settle over time, while the ZVI colloids are designed to settle when injected and react with groundwater passing through. The material injected is intended for long-term operation to control migration of contaminants in groundwater.

The two chemical agents considered for the ICM at Building 25 and CMS at Building 40 were ZVI (i.e., FerroX™) and NZVI (i.e., bimetallic nanoscale particle [BNP]). ZVI, or elemental iron (Fe⁰), is a strong reducing agent that supplies electrons from the iron surfaces in the slurry to an adsorbed halogenated compound (i.e., chlorinated solvents – PCE and TCE). As a result, when chlorinated organic contaminants react with the iron colloids, the contaminant is dechlorinated (i.e., the chlorine atoms are removed) to non-toxic by-products.

FerroX™ (provided by ARS Technologies) consists of micron-sized ZVI particles (approximately 80 micrometer size powder) that are injected as a slurry or as a dry material by either using an open borehole approach or directly into the fractures within the bedrock at a site. Both of these procedures use nitrogen gas as the carrier fluid. Hydrogen gas is generated by the anaerobic corrosion of the metallic iron by water, in which the hydrogen is then used to react with a halogenated hydrocarbon. The metallic iron may act as a catalyst for this reaction between the hydrogen and halogenated hydrocarbon. Impurities in the iron or surface defects may act as that catalyst as well.

Bimetallic nanoscale particles (provided by PARS Environmental) consists of submicron-sized (<10⁻⁶ meter) particles of ZVI with a trace coating of noble metal catalyst (typically palladium or platinum). The noble metal catalyst improves the reactivity of the iron by creating a second metal, in addition to the metallic iron, to catalyze the dehalogenation reactions. BNPs can rapidly destruct recalcitrant contaminants in-situ or ex-situ through the reduction-oxidation (redox) process, in which the contaminant serves

as the electron acceptor. Typically, BNPs are injected via gravity feed (into monitoring wells) or pressure injection (into monitoring wells or by geoprobe) into the subsurface as a slurry at a low concentration (0.1 percent) of the total volume of injected slurry, which helps minimize the potential for clogging of a water-bearing zone. The use of BNPs can also stimulate the growth of an anaerobic microbial community capable of enhanced degradation of certain recalcitrant contaminants by creating strong negative redox conditions within the injection zone.

Target contaminant groups for Ferox™ and BNPs are CVOCs and leachable heavy metals (e.g., chromium and arsenic). BNPs have also been used to remediate groundwater contaminant plumes containing halogenated herbicides and pesticides, perchlorate, PCBs, and nitroaromatics. There have been many field demonstrations and pilot studies conducted in the overburden and bedrock at manufacturing and military sites that have showed decreases in high concentrations of halogenated aliphatics (i.e., PCE, TCE, DCE, and VC) in the groundwater by using ZVI and NZVI technologies. Of the halogenated aliphatics, cDCE and VC react relatively slowly in the presence of ZVI.

Factors that may limit the applicability and effectiveness of the process include:

- Production and accumulation of chlorinated byproducts due to the low reactivity of iron powders toward lightly chlorinated hydrocarbons (i.e., cDCE and VC).
- Iron colloids may lose their reactive capacity due to the precipitation of metal hydroxides and metal carbonates on the surface of the iron colloids, requiring re-injection of the iron periodically.
- Site-specific factors (e.g., carbonate, oxyanions, chloride, dissolved oxygen, alkalinity, and nitrate concentrations) of groundwater can affect the long-term life of the iron filings and iron reactivity during dehalogenation reactions.
- Duration of remediation of the entire plume may be long depending on the speed of the natural flow of the contaminant plume passing through the slurry.
- Iron filing slurries will treat contaminated groundwater in the overburden and in bedrock fractures, but not in the pore spaces of the bedrock matrix.
- Subsurface characteristics (e.g., soil type, grain sizes, permeability, subsurface obstructions, depth of groundwater, depth to bedrock, etc.) may all hinder the contact time between the contaminant and the iron colloids and slow down the rate of contaminant plume remediation.
- The injections must be designed to intersect the preferential groundwater flow paths because the remediation of the contaminant plume is dependent on the contact between the iron filings and the contaminants.
- Contaminants may be degraded to a product that is more hazardous than the original contaminant (i.e., byproducts of TCE, which includes cDCE and VC).

At both Building 25 and Building 40 at the MMA, most or all of the CVOC contamination is located in the bedrock. Therefore, the most appropriate remedy to successfully treat the contaminated plume in the bedrock would need to address the VOC mass in fractures as well as the VOCs in the rock matrix. ZVI and NZVI are not well suited for treating CVOCs concentration in the bedrock matrix. Given this, the use of iron injections was eliminated from consideration.

3.3.3.5. No Action

A no action response would include no remedial measures or monitoring. There are no inherent costs associated with a no action remedial response for a contaminated groundwater plume. The no action alternative would be the same as MNA, without monitoring, to demonstrate reductions in CVOC concentration. As such, a no-action response was not considered further.

3.3.3.6. Evaluation Criteria

Based on the evaluation of the above-mentioned technologies for the treatment of CVOCs in the groundwater at Buildings 25 and 40, data collected during pilot studies, and discussions with the NYSDEC, USEPA, and NYSDOH, the most beneficial and cost-effective in-situ remedial technologies for corrective measures were enhanced bioremediation through the injection of HRC[®] into the overburden and bedrock at Building 25 and ISCO through the injection of potassium and sodium permanganate into the bedrock at Building 40. Both remedial technologies were selected in conjunction with subsequent monitored natural attenuation of the CVOCs in groundwater. The remaining technologies were eliminated from consideration for the reasons summarized below. In general, these remedial technologies were eliminated based on their inability decrease the CVOC concentrations in the bedrock matrix (source area).

- Containment: May prevent off-site migration, but treatment time not acceptable (typically on the order of hundreds of years for bedrock sites) and the lack of impacted downgradient receptors.
- Fenton's Reagent (ISCO Treatment): Oxidant is fast-reacting and does not remain in the subsurface for long periods of time.
- Iron Injection: Not capable of treating bedrock matrix contamination.
- No Action: Impacted areas where contamination remains must be monitored to ensure that potential receptors are not affected.

3.3.4. Vapor Intrusion

The following corrective measures technologies were retained for consideration for buildings impacted by soil vapor intrusion of the chlorinated VOCs.

1. Subsurface Depressurization;
6. Positive Pressure; and