7. Air Filtration.

3.3.4.1. Subsurface Depressurization

Subsurface depressurization systems (also commonly referred to as sub-slab depressurization systems) are the most common remedy for vapor intrusion mitigation. Buildings typically have a lower air pressure than the surrounding soil, particularly in the basement, creating a pressure gradient into the building that allows vapor intrusion to occur. A subsurface depressurization system prevents vapors from entering a building by creating a negative pressure field beneath the building, thereby preventing flow of vapors into the building. Subsurface depressurization systems can either be passive or active. An active system achieves lower subsurface air pressure by using a fan to draw air up from below the slab, while a passive system achieves lower subsurface air pressure by using only the convective flow of air created by connecting the sub-slab environment directly to the atmosphere.

Both active and passive systems have to be checked and maintained regularly to make sure they are performing as designed, although maintenance of active systems is more involved than that of passive systems. The period of performance for these systems is indefinite unless the source of the vapors is completely eliminated.

Subsurface depressurization systems were considered to applicable to Buildings 20, 21, 22, 25, 114, 120, 121, and 130 as these buildings were built with relatively modern foundations that included concrete slabs. However, subsurface depressurization was not considered to be applicable to Building 40 as it has an early 1800s field-stone foundation and earthen floors – most of which are no longer accessible due to modifications to the building over the last 200 years.

3.3.4.2. Positive Pressure

Heating, Ventilation, and Air Conditioning (HVAC) system modifications may be implemented to maintain adequate positive pressure within at least the lowest level of a structure (and all levels in contact with soil) to mitigate vapor intrusion. Older structures, however, rarely exhibit the requisite air tightness to make this approach cost effective. If sufficient positive pressure within the structure can be consistently maintained, then advective flow from the subsurface into the structure can be effectively eliminated. Most forced air heating and cooling systems only operate as needed. To implement positive-pressure vapor intrusion mitigation, the HVAC systems would require modification to run continuously to maintain a constant pressure within the structure.

Due to the age of the affected building in the MMA, which is greater than 50 years at a minimum, as well as the lack of forced air HVAC systems in most of the building, positive pressure mitigation was not considered to be applicable.

3.3.4.3. Air Filtration

The term air filtration is used as a general term to incorporate all remedial technologies in which air is passed through a filter (typically particulate filters or granular activated carbon and/or reactive media) to remove contaminants prior to discharge back into the space. In buildings, the filters can be incorporated as modules into an existing HVAC system or be installed within stand-alone air filtration units that recirculate air within the building.

Integrating activated carbon filtration modules into a preexisting or new HVAC system will be dependent on construction of the system, capacity of the air handling units to handle the pressure-drop across the filtration media, the size of the area being treated, accessibility to the components of the system, piping required, structural requirements and limitations, and the size and type of filtration media.

Indoor air filtration was considered to be applicable for the mitigation of vapor intrusion in Building 40 since the use of subsurface depressurization and/or HVAC modification were not considered to be applicable to the building. However, modification of the existing HVAC systems in the building to include filters was not possible due to limitation on the capacity of the air handlers and the distribution of the system in affected areas of the building. Therefore, the installation of stand-alone air filtration units placed in, and/or ducted to, the affected areas of the building, was selected as the corrective measure for vapor intrusion mitigation in Building 40.

4. Building 25 Groundwater (SWMU 5 and Vapor Degreasers)

4.1. Background

As discussed in Section 2.0, the results of groundwater sampling conducted during the RFI, site-wide LTM program, and the various CMS studies at the MMA indicate that VOC contamination in groundwater at Building 25 is primarily located east and southeast of the building (Figure 2-3), coincident with the groundwater flow direction in this area of the MMA. The contamination primarily consists of chlorinated solvents, such as PCE, TCE, VC, 1,1-DCA, and 1,1,1-TCA, which exceed the corresponding NYSDEC Class GA Standards in the overburden, weathered bedrock, and bedrock groundwater. To address the CVOCs in groundwater, HRC® was injected into the overburden and bedrock in the area east of Building 25 in February 2004. This Pilot Study was conducted in accordance with the Building 25 Pilot Study Work Plan.

Reductive dechlorination is the most important process in the natural biodegradation of chlorinated solvents (i.e., PCE and TCE). For reductive dechlorination to completely degrade CVOCs, such as PCE and TCE to ethene in anaerobic (oxygen depleted) environments, the geochemical conditions in the subsurface must be ideal and the availability of microorganisms that are responsible for degradation must be present. Figure 4-1 shows the reductive dechlorination pathways for various chlorinated solvents, including those present in the groundwater at Building 25. The products of the intermediate (TCE, cDCE, 1,1-DCA, chloroform, and methylene chloride) and complete (chloride, carbon dioxide, ethane, ethene, and water) reductive dechlorination of CVOCs are dependent on the chemical structure of the parent compound.

Electron acceptors (CVOCs), electron donors (sulfate, nitrate, ferric iron, and methane), a reducing environment (oxidation reduction potential [ORP] less than 50 millivolts [mV]), an anaerobic environment (dissolved oxygen [DO] less than 2.0 mg/L), carbon source, and microbes (reductive dechlorinators) are all needed for reductive dechlorination to occur. The most important of these prerequisites is the presence of microbes that utilize hydrogen to dechlorinate VOCs (reductive dechlorinators) in anaerobic environments. However, another type of microbe, methanogens, competes with reductive dechlorinators in anaerobic environments for hydrogen, which is produced by the microbial consumption of carbon in the subsurface.

Based on data collected during the RFI and LTM program, aquifer conditions at Building 25 were generally favorable for the degradation of CVOCs in both the overburden and bedrock groundwater, except for the low concentrations (2 mg/L) of dissolved organic carbon (DOC) in the groundwater samples. A lack of carbon in the subsurface could potentially limit the microbial processes that result in complete reductive dechlorination. HRC® was selected as an interim corrective measure, for the reasons listed in Section 3.0, to enhance the natural attenuation processes in the overburden and bedrock groundwater at Building 25 by adding carbon to the system, thereby promoting the reductive dechlorination of the CVOCs in the groundwater. An overview of natural attenuation and reductive dechlorination as well as the specific details regarding the Pilot Study are presented in the Building 25 Pilot Study Work Plan.

4.2. Pilot Study Implementation

The Building 25 Pilot Study was conducted to:

- Assess the degree to which CVOCs were present in the overburden and bedrock groundwater;
- Evaluate the effectiveness of HRC® as an interim corrective measure for the overburden and bedrock groundwater;
- Demonstrate that HRC® can be efficiently delivered and distributed into the overburden and bedrock treatment zones;
- Reduce contaminant concentrations and mass in the affected areas; and
- Assess the geochemical and biological conditions of the subsurface to gage whether or not reductive dechlorination of CVOCs could continue in this environment long-term.

In general, the Pilot Study consisted of one HRC® injection, in which HRC® was applied directly to the overburden and bedrock groundwater zones. The purpose of this injection event was to demonstrate that HRC® could effectively be injected into the subsurface and stimulate the reduction of CVOC concentrations in the groundwater.

4.2.1. HRC® Injections

4.2.1.1. Overburden HRC® Injection

A direct-push drilling rig was used to inject HRC® into 35 temporary injection points at a depth of 15 to 17 feet bgs at Building 25 (Figure 2-3). The injections were conducted by Zebra Environmental Corporation (Zebra) between February 4 and 7, 2002. The injection points were located on a 50 foot by 75 foot grid pattern over the area of contaminated overburden groundwater in the vicinity of Building 25. Thirty-eight pounds of HRC® was injected into each delivery point, yielding a total volume of approximately 1,350 pounds of HRC® injected in the overburden. Once the injection was completed, the delivery points were backfilled with a bentonite/sand mix and capped with asphalt cold-patch.

4.2.1.2. Bedrock HRC® Injection

On February 8, 2002, six bedrock injection wells (Figure 2-3) were filled with HRC®. The HRC® was first injected under pressure into injection well IW-6. However, the HRC® did not flow into the formation, even at pressures as high as 2,000 pounds per square inch (psi). As a result, the HRC® was passively injected into the six bedrock injection wells by evacuating the groundwater in the injection wells and filling them to the ground surface with HRC®. Each injection well was filled with 420 to 450 pounds of HRC®, yielding a total injected volume of approximately 2,600 pounds of HRC®.

4.3. Pilot Study Results

Details of the Building 25 Pilot Study results are presented in the *Pilot Study Report – Building 25 – HRC Injection, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated March 2006 (Malcolm Pirnie 2006). The Pilot Study was monitored and measured by the following criteria:

- Dissolved oxygen (DO) concentrations;
- Oxidation reduction potential (ORP);
- Trends in electron donor concentrations, including nitrate, sulfate, ferric iron, and methane;
- Trends in target chlorinated organic contaminant concentrations;
- Evidence of the presence of HRC® in the subsurface; and
- Trends in dissolved gases (i.e., ethane, ethene, and methane) concentrations.

4.4. Post-Pilot Study Results

As part of the site-wide LTM program, groundwater samples have been collected from the four Building 25 Pilot Study monitoring wells from the end of study through the present. These samples were analyzed for VOCs, geochemical parameters, and indicator parameters. The pilot study found that thegeochemistry and presence of electron donors in the groundwater at Building 25 after the completion of the Pilot Study were adequate for reductive dechlorination of CVOCs to continue.

As shown on Figure 4-3, the concentrations of PCE, TCE, cDCE, and VC have continued to decrease or have remained stable at the concentrations measured during the last Pilot Study monitoring event in May 2004. By the end of the Pilot Study, the total sum of CVOCs decreased by 31 to 99 percent, depending on the sampling location. In addition, the relative proportion of the parent CVOC (i.e., PCE or TCE) decreased by more than 38 percent at all locations.

4.5. Conclusions

Based on the data collected during and after the Pilot Study, the injection of HRC® was successful in promoting the biodegradation of the PCE and TCE in both the overburden and bedrock groundwater through reductive dechlorination. This conclusion is supported by the following data.

- HRC® was successfully delivered and distributed into the overburden and bedrock groundwater as shown by the increase in DOC concentrations at three of the four monitoring wells studied during the Pilot Study and the detection of HRC® at MW-7, the most downgradient bedrock well.
- By the end of 2005, the HRC® reduced the total CVOC concentrations by 76 and 99 percent in the two bedrock monitoring wells (MW-2 and MW-7), and by 34 percent in overburden monitoring well MW-3.
- The CVOC concentrations at MW-2, MW-3, and MW-7 have not shown significant rebounding and are remaining relatively stable, over six years after the HRC® injection.
- The geochemistry of the overburden and bedrock groundwater was conducive to the reductive dechlorination of PCE and TCE into its daughter products (i.e., cDCE, VC, and ethene).
- Trends in the concentration of daughter products and the concentrations of dissolved gases in the groundwater indicate that complete degradation of the CVOCs was occurring during the Pilot Study and is still occurring after the Pilot Study.
- Concentrations of CVOCs in the monitoring well MW-7, located downgradient of the HRC barrier injection wells were significantly reduced to concentrations less than NYSDEC Class GA Groundwater Standards.

These results, combined with the fact that HRC® was still present in the subsurface at the conclusion of the three-year Pilot Study, and that concentration trends for CVOCs, geochemical parameters, and electron donors are indicative of ongoing reductive dechlorination, indicate that biodegradation of the CVOCs in the groundwater at Building 25 will continue in the future. This conclusion has been supported by groundwater results from LTM monitoring events conducted from 2006 through 2010. Since the CVOCs in the groundwater at Building 25 are localized to the Pilot Study Area and are not migrating beyond the WVA property boundary, long-term monitoring accompanied by the ongoing natural attenuation is recommended as the final corrective measure for the CVOCs in the Building 25 groundwater.

5. Vapor Intrusion

5.1. MMA-Wide

As discussed in Section 2.2.2, the WVA performed a vapor intrusion investigation within, and adjacent to, the MMA and adjacent to the Siberia Area of the WVA. This work was performed in two phases: November 2007 and February 2008. The results of the investigations were presented in the *Data Summary Report – 2007 Vapor Intrusion Evaluation, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated December 2007 (Malcolm Pirnie 2007), and the *Vapor Intrusion Investigation Report, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated August 2008 (Malcolm Pirnie 2008). 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 was 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, 124, and 126. However, eight building were found to require mitigation. These buildings are summarized in Table 5-1 below.

Table 5-1 – Buildings Requiring Soil Vapor Mitigation

Building	Impacted Media	Target Chlorinated VOCs
20	Sub-Slab Soil Vapor	PCE, TCE, TCA
21	Sub-Slab Soil Vapor	TCE
22	Sub-Slab Soil Vapor	TCE
25	Indoor Air, Sub-Slab Soil Vapor	TCE, TCA
114	Indoor Air, Sub-Slab Soil Vapor	PCE, TCE
120	Sub-Slab Soil Vapor	PCE, Carbon Tetrachloride
121	Sub-Slab Soil Vapor	TCE
130	Sub-Slab Soil Vapor	TCE

As discussed in Section 3, the corrective measures for these buildings consisted of the installation and operation of subsurface depressurization systems (SSDSs) at each of the eight buildings identified in Table 5-1. Due to the large differences in the size, layout, and use of the buildings, the type of, and operational parameters for, the SSDSs varied from building to building. The design of each SSDS was based on the results of pilot testing conducted in 2008. The results of the pilot testing, as well as the design of the SSDSs and the operations and maintenance requirements, are presented in the *Vapor Intrusion Interim Corrective Measures Work Plan, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated July 2009 (Vapor Intrusion ICM Work Plan) (Malcolm Pirnie 2009).

The SSDSs in the eight buildings were installed in and activated in 2010. The results of the installation and the associated startup testing are presented in *Vapor Intrusion Interim Corrective Measures Construction Certification Report, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated September 2010 (Malcolm Pirnie 2010). As discussed in the certification report, the systems are operating as designed and are successfully mitigating vapor intrusion into the buildings. Based on this information, SSDSs are recommended as the final corrective measure for vapor intrusion in Buildings 20, 21, 22, 25, 114, 120, 121, and 130. Monitoring and maintenance of the systems will be continued in accordance with the Vapor Intrusion ICM Work Plan.

5.2. Building 40

5.2.1. Background

Between February 2003 and February 2006, investigations were conducted to assess whether CVOCs associated with the bedrock groundwater contamination in the vicinity of Building 40 were present in the soil vapor and indoor air beneath and/or within the building. The results of these investigations were submitted to the NYSDEC, USEPA, and NYSDOH in the following documents:

- *Work Plan for Ambient Air Sampling and Basement Ventilation Testing, Building 40, Watervliet Arsenal, Watervliet, New York*, dated August 2003 (Malcolm Pirnie, 2003c);
- *Revised Work Plan, Indoor Air and Soil Gas Testing, Building 40, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated January 2004 (Malcolm Pirnie, 2004c);
- *Additional Indoor Air Sampling, Building 40, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated August 2004 (Malcolm Pirnie, 2004d);
- *Additional Soil Gas Testing and Soil Sampling, Building 40, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated April 2004 (Malcolm Pirnie, 2004e)

A summary of these investigations is provided below.

5.2.2. Initial Investigation

This investigation was conducted to initially assess whether CVOCs associated with the bedrock groundwater contamination in the vicinity of Building 40 were present, and to what extent, in the indoor air and/or soil gas in the Building 40 basement area. Low concentrations (i.e., less than 3.0 micrograms per cubic meter [$\mu g/m^3$]) of VC, cDCE, TCE, and PCE, as well as BTEX were detected in the basement indoor air samples (Table 5-1).

5.2.3. Additional Investigations

Additional indoor air and soil gas investigations were conducted in September 2003, February/March 2004, April/August 2004, and February 2006 to further assess whether CVOCs associated with the bedrock groundwater contamination in the vicinity of Building 40 were present, and to what extent, in the soil vapor and indoor at Building 40. As part of these investigations, the following activities were performed:

- A confounding source survey was conducted to identify any potential or possible sources of CVOCs or petroleum compounds in the vicinity of the investigation area.
- Sixty-four indoor air samples were collected.
- Thirty soil gas collection points were installed at locations around Building 40 and sampled.
- A basement ventilation test was conducted.
- Three air samples were collected from three of the eight sealed openings along the eastern foundation wall of Building 40.
- Five air samples were collected from two vents on the west wall and three vents on the east wall (wall facing Interstate 787).
- Nine vents were inspected by video for total depths and structural information.

5.2.3.1. Indoor Air Sampling

Sixty-four indoor air samples were collected in Building 40 during the various investigations. TCE concentrations in indoor air samples greater than the NYSDOH action level of 5.0 $\mu g/m^3$ were measured in the following locations (Figure 5-1):

- First floor south conference room;
- First floor Unit 6;
- Second floor south section; and
- Second floor Unit 2.

5.2.3.2. Soil Gas Sampling

Thirty soil gas points were installed and sampled around Building 40. Each point was constructed with a "shallow" soil gas point constructed approximately five feet bgs and a "deep" soil gas point constructed approximately 10 feet bgs. In general, CVOC detections in the soil gas were localized in nature and coincided with areas of elevated TCE and PCE concentrations in groundwater (Figure 5-2).

5.2.3.3. Foundation Sampling

There were eight locations noted (Figure 5-2) along the eastern foundation walls of Building 40 where apparent former openings to the area below the current first floor exist. These former openings have been sealed with brick. Three of the sealed openings were penetrated to evaluate the nature of the space below the first floor. While penetrating the sealed openings it was found that the area behind the sealed openings had been backfilled. As a result, the soil gas behind the foundation wall was sampled by installing a horizontal soil gas point into the backfill material behind the wall. The soil gas points were sealed to the foundation and sampled. No CVOCs were detected in any of the foundation opening samples.

5.2.4. Corrective Measures

As discussed previously, due to the construction and age of the Building 40 foundation, the use of subsurface depressurization was not considered to applicable. Therefore, indoor air filtration was utilized as the mitigation measure for the Building 40 indoor air. The mitigation measure consisted of the installation of eight air filtration units (AFUs) in the impacted areas of the building as follows:

- **Unit 6 Body Forge Exercise Area**: Two, 2,000 cubic feet per minute (CFM) capacity, stand-alone Circul-Air AFUs equipped with granular activated carbon/permanganate filter media for CVOC treatment.
- **Unit 6 Turret Lab**: Two, 2,000 cubic feet per minute (CFM) capacity, stand-alone Circul-Air AFUs equipped with granular activated carbon/permanganate filter media for CVOC treatment.
- **South Conference Room**: One, 1,000 cubic feet per minute (CFM) capacity, Circul-Air AFU equipped with granular activated carbon/permanganate filter media for CVOC treatment and connected to the conference room via dedicated supply and return air ducts.
- **Unit 2 Second Floor**: Three, 2,000 cubic feet per minute (CFM) capacity, Circul-Air AFUs equipped with granular activated carbon/permanganate filter media for CVOC treatment and connected to the Unit 2 office areas via dedicated supply and return air ducts.

The AFUs were installed in 2006 and were activated in January 2007. The WVA monitors the operation of the units during monthly inspections and during semi-annual filter media testing. Filter media is replaced based on the results of the testing. Based on the performance of the systems to date and the impracticability of installing subsurface depressurization systems, the indoor air filtration units are the recommended final corrective measure for vapor intrusion at Building 40.

6. Building 40 Bedrock Groundwater (SWMU Vapor Degreasers)

6.1. Background

Chlorinated volatile organic compounds, composed primarily of PCE, trichloroethene TCE, cDCE, and, to a lesser extent, VC, were detected in the bedrock aquifer in the vicinity of Building 40 during the RFI. As a preliminary step in the CMS process, an additional investigation was conducted in the Building 40 area to further define the extent of CVOC contamination in the bedrock aquifer. The results of this investigation are contained in the *Corrective Measures Data Gap Study Summary Report, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York* (Malcolm Pirnie 2001) (Data Gap Study Report).

In 2001 and 2002, an in-situ chemical oxidation pilot study (Pilot Study) was performed in the Building 40 area to evaluate the degree to which the CVOCs in the bedrock groundwater could be treated using potassium permanganate (KMnO4). The Pilot Study was performed in accordance with the *Work Plan for Building 25 and Building 40 Pilot Studies, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York* (Malcolm Pirnie, 2001a). The Pilot Study included multi-level monitoring well installation, rock core sampling, several phases of potassium permanganate (KMnO4) injection, and monitoring to evaluate both the distribution of potassium permanganate and CVOC destruction in the bedrock groundwater.

A Human Health and Ecological Exposure Assessment (Exposure Assessment) was performed for the MMA in conjunction with the CMS Data Gap and Pilot Studies. The results of the Exposure Assessment have been provided to the NYSDEC and USEPA in the *Draft Exposure Assessment, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York* (Malcolm Pirnie, 2003). Based on the information in the draft Exposure Assessment, there is no identified risk to human health or the environment associated with contact, ingestion, or discharge of the groundwater. However, as discussed previously, an exposure pathway related to CVOC vapor intrusion into the indoor air of Building 40 was identified and mitigated.

Studies of the ambient air quality inside Building 40, and the soil gas quality around the building, were conducted to evaluate possible vapor intrusion pathways. The studies showed an area of elevated CVOC concentrations in the shallow soil gas in the courtyard adjacent to Unit 6 of Building 40. Historical information indicates the former presence of a vapor degreaser in Unit 6. Based on these data, it is suspected that the source of the CVOCs in the subsurface in the Building 40 area originated in the Unit 6 area.

Extensive hydrogeologic characterization studies were performed in the bedrock aquifer in the Building 40 area during the RFI and Data Gap Study. These studies included discrete zone packer testing, down-hole geophysical profiling, video and acoustic televiewer profiling, and intra- and cross-borehole flow testing. The results of these studies are detailed in the *United States Geological Survey (USGS) Open-File Report entitled Characterization of Fractures and Flow Zones in a Contaminated Shale at the Watervliet Arsenal, Albany County, New York: USGS Open File Report 01-385* (Williams and Paillet, 2002) and in the Data Gap Study Report. Based on the results of the hydrogeologic studies, groundwater in the bedrock aquifer in the Building 40 area flows along discrete, generally interconnected, fracture pathways. The results of the cross-borehole flow testing indicate that a highly transmissive fracture or series of fractures connects several of the wells in the Building 40 area. More than 80 discrete fractures were identified during the testing. However, the testing also demonstrated that other, less direct, connections exist between the monitoring wells installed in the Building 40 Area.

During the CMS investigations, rock core samples were collected from monitoring wells located in the central portion of the CVOC-impacted area. These samples were analyzed for rock matrix pore water VOC content by the University of Waterloo (UW). The analysis revealed that matrix pore water CVOC concentrations, some approaching aqueous solubility, were present in the rock cores from approximately 25 to 150 feet bgs.

6.2. Site Conceptual Model

The conceptual model for the bedrock groundwater in the Building 40 area is as follows.

CVOCs are present in the bedrock aquifer in the Building 40 area. Dissolved-phase CVOC concentrations indicating the potential presence of dense non-aqueous phase liquid (DNAPL), have been detected in the bedrock groundwater. Advective transport of the CVOCs in the bedrock aquifer takes place through a well connected fracture network that extends to a depth of approximately 150 to 200 feet bgs. This depth has been confirmed by both fracture groundwater and rock matrix CVOC analysis. Based on field observations, groundwater below approximately 150 feet is also affected by the presence of naturally-occurring hydrogen sulfide and methane gas. The original source of the CVOCs in the bedrock groundwater is presumed to be located in the northeastern portion of the building, between Units 5 and 6. Since significant CVOC concentrations were not detected in the overburden soil in this area, it is possible that the release occurred through a subsurface storm sewer that was once connected to floor drains in Unit 6 of Building 40.

Although fractures provide the only pathway for advective transport of groundwater and CVOCs through the bedrock aquifer, the ratio of the void space due to the presence of fractures to the bulk rock volume ("fracture porosity") is several orders of magnitude less than the matrix porosity of the rock itself – meaning that the capacity of the rock matrix to store CVOCs is orders of magnitude greater than the storage capacity in the fractures. This matrix storage capacity creates a diffusive gradient by which CVOCs present at high concentrations in the fractures can diffuse into the bedrock pore spaces. Thus, although DNAPL may still exist in some fractures, the majority of the DNAPL that was initially present in the fractures has likely dissipated due to dissolution and diffusive mass transfer to the rock matrix -- causing nearly all the VOC mass to now reside in the rock matrix and not in the bedrock fractures. This concept has been confirmed by the presence of high concentrations of CVOCs in bedrock core samples obtained during the pilot and CMS studies. Given these data, and the lack of any current surficial sources, it is presumed that the shale bedrock itself is the continuing source of the CVOCs in the groundwater

This site conceptualization indicates that the only truly effective remediation technologies for the fractured bedrock aquifer are those that will treat the CVOC mass in the rock matrix in addition to treating the CVOC mass in the fractures. Failure to treat the CVOC mass in the matrix (i.e., the source area) will result in a continuous diffusive transfer of CVOCs out of the bedrock into the groundwater in the fractures.

6.3. Pilot Study

Details for the Building 40 bedrock groundwater in-situ chemical oxidation pilot study (Pilot Study) are presented in the *Work Plan for Building 25 and Building 40 Pilot Studies, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York* (Malcolm Pirnie, 2001a) and the *Building 40 In-Situ Chemical Oxidation Pilot Study Report, Watervliet Arsenal, Watervliet, New York, dated April 2004* (Malcolm Pirnie, 2004) (Building 40 Pilot Study Report). A summary of the Pilot Study is presented below.

The objectives of the Building 40 bedrock groundwater corrective measures pilot study were to:

- Evaluate whether potassium permanganate could be effectively delivered and distributed through the bedrock treatment area;
- Confirm that CVOCs in the bedrock groundwater could be oxidized by the permanganate;
- Assess the persistence of the permanganate in the subsurface; and
- Estimate the degree and rate of diffusion of permanganate into the shale bedrock matrix.

In general, the Pilot Study consisted of two phases of potassium permanganate (KMnO4) solution application. The purpose of the first phase was to evaluate whether the KMnO4 solution could be efficiently injected into a major transmissive zone and effectively distributed along this zone in a relatively short period of time. The second phase was a longer-term permanganate delivery designed to flood certain areas with sufficient permanganate to allow for diffusion into the rock matrix.

6.3.1. Permanganate Distribution and CVOC Destruction

Single-point injections of potassium permanganate in the affected area resulted in distribution of permanganate both laterally and vertically throughout the bedrock aquifer in the Pilot Study area. CVOC concentrations in the bedrock groundwater were reduced in monitoring zones where permanganate was present. Based on rebound monitoring conducted after the completion of injections, permanganate residence time in the fractures was approximately two to three months.

6.3.2. Permanganate Matrix Invasion

Laboratory testing was conducted to measure the rate of permanganate invasion into the shale bedrock. This was accomplished by submerging rock core samples in KMnO4 solution for a period of time during which diffusion into the core would take place. Preliminary analysis indicates that the permanganate has successfully invaded the shale bedrock matrix, but that the invasion distances into the shale during the six month test period were less than100 microns.

6.3.3. Pilot Study Conclusions

The results of the Pilot Study indicated the following.

1. The vast majority of the CVOC mass in the bedrock aquifer in the Building 40 area is entrained in the shale bedrock matrix pore spaces.
8. Permanganate could be distributed both vertically and horizontally throughout the treatment area using a small number of injection points.
9. Permanganate reduced the concentration of CVOCs in the bedrock groundwater in the short term.

Based on the data collected during the Pilot Study, permanganate was selected as the corrective measures technology for treating the CVOC contamination in the Building 40 bedrock groundwater.

6.4. Corrective Measures

Details of the Building 40 Bedrock Groundwater Corrective Measures (CM) are presented in the following documents. The scope and results of the CM are summarized herein.

- *Corrective Measures Work Plan, Building 40 Bedrock Groundwater, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated June 2004 (Malcolm Pirnie, 2004) (CM Work Plan);

- *Corrective Measures Monitoring Program, Building 40 Bedrock Groundwater, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated August 2004 (Malcolm Pirnie, 2004a) (CMMP);
- *Corrective Measures Installation and Startup Report, Building 40 Bedrock Groundwater, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated August 2006 (Malcolm Pirnie, 2006) (CM Startup Report); and
- *Corrective Measures Performance Evaluation Report, Building 40 Bedrock Groundwater Corrective Measures, Main Manufacturing Area, Watervliet Arsenal, Watervliet, New York*, dated December 2008, revised September 2009 (Malcolm Pirnie 2008 & 2009)(CM Performance Evaluation Report).

6.4.1. Corrective Measures Summary

The CM treatment program included injections of sodium permanganate (herein referred to as permanganate) and groundwater sampling at the WVA property line compliance boundary.

In accordance with the approved CM Work Plan, the Corrective Action Objective (CAO) for the CM Program was to reduce the concentration of hazardous constituents in groundwater migrating from the site to New York State and Federal groundwater standards, or approved alternate concentration limits (ACLs) developed for the site. However, given the likely presence of DNAPL in the fractured rock at the site, it was recognized by all parties that the achievement of the CAO may require an extensive time period and may not be achievable using currently available technologies. Accordingly, the CM program was subject to the following Performance Criteria, through which the CAO may be achieved over the long-term as a result of source reduction:

1. Permanganate Distribution: The permanganate must be well distributed to and within the boundary monitoring wells within one year after the initiation of full scale injections.
2. Permanganate Residence Time: The permanganate must persist for at least 30 days after injection in the boundary monitoring wells within two years after the initiation of full scale injections.

If these performance criteria were not met, the WVA was required to perform an evaluation as to whether the permanganate corrective measures, or any other potential corrective measures, are feasible for the site.

The corrective measures were initiated in September 2004 with injections on the west side (upgradient) of Building 40. Full scale injections into all five injection wells were initiated in August 2005. The maximum permanganate distribution in the compliance boundary monitoring wells was achieved during the first full-scale injection event in August 2005 when permanganate was delivered to nine of the 18 compliance monitoring zones. Beginning with the November 2005 injection event, and in subsequent injection events, injection well clogging limited the amount and/or rate of oxidant that could be delivered to injection wells IW-2 and IW-3. Clogging in these wells, which are located in the central portion of the treatment area, was accompanied by a decrease in permanganate distribution in the compliance monitoring zones. As of the last injection event in September 2006, permanganate residence time was less than 30 days in 16 of the 18 monitoring zones.

Injection well IW-3 was reamed with a roller bit in August 2006 to clear the remains of a partially disintegrated FLUTe™ liner and to attempt to redevelop the well. In September 2006, well IW-2 was mechanically cleaned using a drilling rig equipped with a wire brushing device, and redeveloped using a combination of surging and pumping. Specific capacity testing performed before and after the redevelopment/cleaning indicated that the flow conditions in these wells had not improved significantly. A subsequent injection event in September 2006 confirmed this finding as injections into well IW-2 and IW-3 were limited due to lack of flow and the resulting permanganate distribution was the lowest since full-scale injections were initiated. Temperature and pressure data collected during the injection indicated that the permanganate injections were not influencing all portions of the treatment area. Further attempts to rehabilitate injection well IW-2 in March 2007 using AirBurst® technology did not result in significant increases in specific capacity.

6.4.2. Corrective Measures Evaluation

Based on the failure of the permanganate treatment to meet the CAOs, and in accordance with the CM Work Plan, the WVA evaluated whether any additional technologies were capable of meeting the corrective measures metrics. An evaluation of the VOC mass discharge from the compliance boundary (property boundary) was also conducted. Details of these evaluations are presented in Attachments A and B, respectively, of the CM Performance Evaluation Report.

6.4.2.1. Technology Evaluation

The following corrective measures technologies were screened for their potential effectiveness at meeting the CAO prior to the implementation of the permanganate corrective measures.

1. Monitored Natural Attenuation (MNA)
10. Containment
11. In-situ Enhanced Bioremediation (ISB)
12. In-situ Chemical Oxidation (ISCO)
13. No Action

Of these, in-situ chemical oxidation (ISCO) using permanganate was chosen as the only alternative that was potentially capable of meeting the CAO over the long term through source treatment of the bedrock matrix. Upon the failure of the permanganate corrective measures to meet corrective measures performance metrics, the WVA conducted a technology screening to confirm that there were no new applicable corrective measures technologies that have become available since the initial screening documented in the CM Work Plan evaluations. This evaluation included in-situ thermal remediation (ISTR) technologies, which had been developed at the time of the initial screening, but were not included in the Work Plan. The evaluation concluded that there were no currently available technologies, including ISTR, that were capable of meeting the CAOs under the site conditions.

6.4.2.2. Mass Discharge Evaluation

The purpose of the mass discharge evaluation was to assess the changes in VOC mass discharge across the compliance boundary since the discontinuation of permanganate injections, and the effect of new hydraulic conductivity estimates on the VOC mass discharge due to clogging associated with the precipitation of manganese dioxide particulates from the injection solution.

Compliance boundary VOC mass discharge estimates utilized during the corrective measures program and in the CM Performance Evaluation were estimated for each compliance monitoring zone using the hydraulic conductivity (K) values calculated for fractures that had detectable flow during the July 2004 geophysical testing. The K values utilized for the VOC mass discharge calculations were the sum of the individual K values for fractures with detectable flow that intersected each compliance monitoring zone at the time of the geophysical testing in 2004. Mass discharge estimates were calculated using the following assumptions:

- Discharge Zone Thickness: Set as the thickness of the screened interval in each compliance monitoring zone.
- Hydraulic Gradient: Set at 0.003 ft/ft based on the hydraulic gradient in the Building 40 area calculated from WVA-wide water table groundwater elevations.
- Horizontal Length of Discharge Zone: Set as the distance between compliance monitoring wells.
- VOC Concentration: Set at the total VOC concentration in each compliance monitoring zone during each monitoring event.

Table 6-1, below, presents changes from baseline in the estimated compliance boundary VOC mass discharge after each injection event. As shown in the table, the estimated compliance boundary VOC mass discharge in June 2010 was approximately 66 percent of the baseline using the 2004 K estimates and the was the lowest mass discharge estimate measured during the CM program.

	Table 6-1: Compliance Boundary VOC Mass Discharge									
	Baseline	**Jan. 2005**	**May 2005**	**Aug. 2005**	**Nov. 2005**	**Mar. 2006**	**Sept. 2006**	**Sept. 2007**	**May 2009**	**June 2010**
Total VOC Mass Discharge (lb/yr)	10.0	10.0	11.5	10.0	6.6	10.6	18.0	13.1	8.5	6.6
% of Baseline VOC Mass Discharge	---	*100%*	*115%*	*100%*	*66%*	*106%*	*180%*	*131%*	*85%*	*66%*

Notes:
lb/yr – pound per year

6.4.2.3. 2009 Hydraulic Conductivity Estimates

It was not possible to re-evaluate fracture / monitoring zone K in the compliance monitoring wells using the geophysical methods employed in 2004 due to the presence of multi-level monitoring wells in the boreholes. Accordingly, standard slug tests were performed in each monitoring zone in October 2007 to estimate the K after three years of permanganate injections. It is important to note that slug tests are not directly comparable to the geophysical testing and may not be appropriate for use in bedrock; however, given the limitations imposed by the presence of the multi-level wells, slug tests were utilized to gain an understanding of the potential changes in K resulting from the generation of manganese dioxide precipitates.

The results of the assessment indicated that the estimated K values in 2007 were generally less than 50 percent of the baseline values measured in 2004. However, several of the 2007 estimated K values were similar in magnitude to, or greater than, the 2004 estimates, which indicates that the slug test results were likely not biased low as compared to the 2004 estimates. These data, recognizing the potential limitations described above, support the conclusion that clogging due to manganese dioxide precipitation has reduced the capacity of the bedrock fractures to transport groundwater through the compliance boundary. This, and (presumably) the CVOC mass reduction accomplished by the permanganate treatment has resulted in a decrease in the VOC mass discharge across the compliance boundary, which was evidenced by the May 2009 and June 2010 sampling results.

6.5. Conclusions

The results of the testing, monitoring, and evaluations support the following conclusions for the Building 40 bedrock groundwater.

1. The permanganate injections conducted to date have not decreased groundwater VOC concentrations at the compliance boundary to less than NYSDEC Class GA standards/guidance values. Testing conducted in 2006 also showed that rock core VOC pore water concentrations have not decreased after two years of injections. However, based on subsequent monitoring, the injections may have reduced the mass discharge of CVOCs at the compliance boundary.
2. The persistent clogging problems indicate that a large portion of the injected permanganate mass was oxidized to insoluble precipitates through interaction with the rock matrix, specifically the reduced sulfur (i.e., pyrite), present in the rock. This interaction with the rock greatly limited the effectiveness of the permanganate injections. Rock core, water level, pressure, and temperature monitoring has shown that the injections are influencing only a portion of the treatment area due to clogging.
3. The CM program failed to achieve the CM Performance Criteria and, therefore, cannot achieve the overall CAO of reduction of VOC concentrations in groundwater to state or federal standards.

Based on these data, and the lack of any other potentially effective remedial technology, achievement of the CAO is not technically feasible using currently available technologies. In accordance with the provisions of the CM Work Plan, the CM Program was discontinued and a final corrective measure of monitored natural attenuation was recommended for the site.

7. Recommended Final Corrective Measures

7.1. Building 25 Groundwater

A combination of long-term monitoring accompanied by the ongoing natural attenuation is the recommended final corrective measure for the groundwater in the Building 25 Pilot Study area. Based on the results and conclusions presented in the Building 25 Pilot Study, the proper geochemistry and nutrient supply necessary for sustaining natural attenuation of CVOCs is present. The CVOCs in the groundwater at Building 25 are also localized to the Pilot Study Area and are not migrating beyond the WVA property; therefore, the recommended final corrective measure should achieve CAOs for the groundwater at Building 25 over the long term.

7.2. Building 40

7.2.1. Vapor Intrusion

The final corrective measure chosen for indoor air in portions of Building 40 that contain TCE concentrations that are greater than the current NYSDOH/NYSDEC action level of 5.0 $\mu g/m^3$ is to continue to treat the indoor air in these areas through the indoor air filtration units installed in 2006 and 2007.

7.2.2. Groundwater

As discussed in Section 6, achievement of the CAO for the Building 40 bedrock groundwater is not technically feasible using currently available technologies. It is therefore recommended that monitored natural attenuation documented through long-term groundwater monitoring be selected as the final corrective measure for the Building 40 bedrock groundwater.

7.3. Vapor Intrusion

Continued operation and monitoring of the subsurface depressurization systems (SSDSs) are recommended as the final corrective measure for vapor intrusion in Buildings 20, 21, 22, 25, 114, 120, 121, and 130.

8. Evaluation of Recommended Final Corrective Measures

As stated in the USEPA Fact Sheet #3: Final Remedy Selection for Results-Based RCRA Corrective Action (USEPA, 2000), final remedies for RCRA Corrective Action facilities should achieve the following three performance standards:

1. Protection of human health and the environment based on reasonably anticipated land use(s) (current and future).
2. Achieve corrective action objectives appropriate to the anticipated land use.
3. Remediate the source of releases.

Within these performance standards, the USEPA has developed evaluation criteria by which each proposed final corrective measure should be judged as acceptable or unacceptable. These evaluation criteria are:

1. Long-term effectiveness
2. Reduction of toxicity, mobility, and volume
3. Short-term effectiveness
4. Implementability
5. Cost
6. Community acceptance
7. State acceptance

An evaluation of each of the proposed final corrective measures with regard to both the performance standards and the first five USEPA evaluation criteria is provided below. USEPA Criteria 5, cost, is not applicable to the WVA as all of the recommended corrective measures have already been implemented as full-scale pilot studies or ICMs. Criteria 6 and 7 are also not evaluated in this report and will be addressed through the preparation and review of the Statement of Basis for the Main Manufacturing Area. A summary of the corrective measures with regard to AOCs is presented in Table 8-1.

8.1. Building 25 Groundwater

Summary
SWMU: Building 25 (SWMU 5) and Vapor Degreaser Units
Corrective Measure: Monitored natural attenuation
Contaminants Treated: CVOCs

8.1.1. Description

Based upon the fact that HRC® was still present in the subsurface at the conclusion of the three-year Pilot Study, and that concentration trends for CVOCs, geochemical parameters, and electron donors are indicative of ongoing reductive dechlorination, it is probable that biodegradation of CVOCs in the groundwater to concentrations less than the CAOs at Building 25 will occur over time. Since the CVOCs in the groundwater at Building 25 are localized to the Pilot Study area and are not migrating beyond the WVA property boundary, the final corrective measure for the CVOCs in the Building 25 groundwater is long-term monitoring through the site-wide long-term monitoring program, accompanied by ongoing natural attenuation.

8.1.2. Comparison to Performance Standards

8.1.2.1. Protection of Human Health and the Environment

The Building 25 groundwater corrective measure will protect human health and the environment by monitoring CVOC concentrations greater than the CAOs in the groundwater limited to the small area east and southeast of Building 25 to ensure that VOCs do not migrate to potential receptors beyond the WVA property boundary. The corrective measure will reduce concentrations of CVOCs in the groundwater and prevent further migration of CVOCs in the groundwater offsite.

8.1.2.2. Achievement of Corrective Action Objectives

This corrective measure will achieve the CAOs by continuing to degrade PCE and TCE through natural attenuation processes to non-toxic byproducts (i.e., carbon dioxide and ethene), ultimately reducing both the concentration and mass of the contaminants in the groundwater.

8.1.2.3. Source Remediation

As stated above, this corrective measure will reduce the concentrations and mass of CVOCs in the overburden and bedrock groundwater in the Building 25 area. The CVOCs in the groundwater are most likely a product of a vapor degreaser that was located in Building 25. This vapor degreaser has been removed and has not been a contributing source of CVOCs to the groundwater for some time.

8.1.3. Comparison to Evaluation Criteria

8.1.3.1. Long-term Effectiveness

This corrective measure will be effective over the long term since there is no longer a contributing source of CVOCs to the subsurface in the Building 25 area and CVOC concentrations greater than the CAOs will continue to decrease through natural attenuation. Long-term monitoring will document the progress of CVOC reduction to concentrations less than CAOs.

8.1.3.2. Reduction of Toxicity, Mobility, and Volume

This corrective measure will reduce the toxicity, mobility, and volume of the CVOCs in the overburden and bedrock aquifers by reducing the CVOC mass, and subsequently reducing concentrations in the groundwater.

8.1.3.3. Short-term Effectiveness

This corrective measure was effective in the short-term in reducing many of the groundwater concentrations to less than CAOs during the Pilot Study and will continue to be effective in sustaining these concentrations.

8.1.3.4. Implementability

The in-situ treatment conducted during the Pilot Study and subsequent long term groundwater monitoring demonstrated that an environment conducive to the natural attenuation of CVOCs is present in the Building 25 area and that CVOC concentrations are decreasing over time.

8.2. Building 40 Vapor Intrusion

<u>Summary</u>
SWMU: Vapor Degreaser Units
Corrective Measure: Stand-alone indoor air filtration units.
Contaminants Treated: VOCs, specifically TCE

8.2.1. Description

As discussed previously, due to the construction and age of the Building 40 foundation, the use of subsurface depressurization was not considered to applicable to address vapor intrusion into the building. Therefore, eight air filtration units (AFUs) were installed in the impacted areas of the building. The AFUs were installed in 2006 and were activated in January 2007. The WVA monitors the operation of the units during monthly inspections and during semi-annual filter media testing. Filter media is replaced based on the results of the testing.

8.2.2. Comparison to Performance Standards

8.2.2.1. Protection of Human Health and the Environment

The Building 40 indoor air and soil gas corrective measures will protect human health and the environment by removing VOCs that migrate to the indoor air from the subsurface.

8.2.2.2. Achievement of Corrective Action Objectives

The CAOs will be achieved by removing VOCs that migrate to the indoor air from the subsurface.

8.2.2.3. Source Remediation

Source remediation will be accomplished in the long term through the natural attenuation of the CVOCs in the underlying bedrock groundwater.

8.2.3. Comparison to Evaluation Criteria

8.2.3.1. Long-term Effectiveness

The corrective measure will be effective over the long term through continuous operation of the AFUs, as documented by the ongoing operations and monitoring program.

8.2.3.2. Reduction of Toxicity, Mobility, and Volume

The corrective measure will reduce the toxicity and mobility of the CVOCs by removing them from the indoor air, thereby preventing exposure.

8.2.3.3. Short-term Effectiveness

This corrective measure has been effective in the short-term by removing the CVOCs from the indoor air.

8.2.3.4. Implementability

The AFUs have already been installed and are currently operating.

8.3. Building 40 Groundwater

<u>Summary</u>
SWMU: Vapor Degreaser Units
Corrective Measure: Monitored natural attenuation.
Contaminants Treated: CVOCs

8.3.1. Description

The USEPA Natural Attenuation Protocol Table 2.3 (USEPA 1998b) contains a screening process to evaluate the potential for reductive dechlorination based on site monitoring data. Using data from groundwater samples collected from monitoring well MW-51 (located in the center of the impacted area) during the RFI and LTM program through 2003 (before the initiation of the permanganate corrective measures) resulted in a screening score of 23, which, according to the protocol, is indicative of strong evidence for anaerobic biodegradation of the chlorinated solvents present in the bedrock groundwater. These data included:

- The presence of relatively high concentrations (greater than 0.1 milligrams per liter [mg/l]) of the dissolved gases ethene and ethane, which are the final end products of the complete degradation of PCE and TCE.
- Low dissolved oxygen levels (less than 1 mg/l) and reducing conditions (reduction-oxidation potential less than 0 mV).

- Low nitrate and sulfate concentrations, which are indicative of the use of the nitrogen and sulfur as electron donors and which are potentially competing electron acceptors at high concentrations.
- Detectable concentrations of ferrous iron, which is indicative of both reducing conditions and the use of ferric iron as an electron donor.

Last, a groundwater sample collected from MW-51 in November 2003 showed the presence of DHC, which, as discussed above, can complete the reductive dechlorination process by converting vinyl chloride to ethene. Based on this information, it is anticipated that concentrations of chlorinated VOCs in the bedrock groundwater will decrease over time through natural attenuation processes.

Monitoring Plan

It is proposed that all zones in compliance boundary monitoring wells MW-82R, MW-83, MW-84R, MW-85R, and MW-86R be sampled for VOCs on an annual basis. Due to the presence of chlorinated VOCs (CVOCs) in the compliance boundary monitoring wells in the Building 40 area, a contingency monitoring plan has been developed in the event that anomalous CVOC concentrations are detected in these wells in the future.

Statistical Trigger

The proposed contingency evaluation protocol utilizes a well and contaminant-specific statistical "trigger" concentration that initiates a contingency evaluation in the event groundwater monitoring data indicates a potential changes in site conditions. This method is currently utilized by the NYSDEC for solid waste landfill monitoring programs to evaluate if a statistically significant release from a landfill has occurred [6 NYCRR Part 360-2.11(c)(5)(i)]. The statistical trigger will be calculated as follows:

1. The results for the COCs in each of the wells from the period of the spring of 2004 through the spring of 2009 were averaged to determine the mean "background concentration". The standard deviation of the "background" data set was also established. The "background" mean and standard deviation will be the basis for all future comparisons.

2. Trigger values were established for each COC in each well as the sum of the background mean plus three times the background standard deviation. This test is commonly used to identify outlying data that fall outside the expected range of values based on a given baseline data set.

3. Monitoring events during which permanganate was present in the Building 40 compliance boundary wells (i.e., assumed zero concentrations) were not included in the calculations.

4. Monitoring events during which the compound was not detected were included as one half of the laboratory reporting limit for that compound.

Contingency Monitoring

Upon receipt of analytical data, the result for each of the COCs will be compared against the statistical trigger concentration. If the data for the COCs in a given well exceed the statistical trigger concentrations the NYSDEC will be notified of the condition within 15 days and potential follow up actions will be determined in consultation with the NYSDEC. If samples from three or more of the Building 40 compliance boundary wells contain COCs at concentrations greater than the corresponding statistical trigger concentrations, verification sampling consisting of quarterly sampling for one year will be conducted, with sampling results provided to the NYSDEC each quarter. The objective of the verification sampling will be to evaluate the potential causes of the increase in COC concentrations; to assess whether changes to the monitoring program are required; and, if necessary, to perform a risk evaluation and technology screening to evaluate potential corrective measures technologies that may be applicable to the site. Based on the results of the verification sampling, potential follow up actions will be determined in consultation with the NYSDEC. Significant increases in the levels of COCs will be discussed in the annual monitoring report and recommendations made for further actions, if necessary.

8.3.2. Comparison to Performance Standards

8.3.2.1. Protection of Human Health and the Environment

The Building 40 groundwater corrective measure will protect human health and the environment by monitoring CVOC concentrations greater than the CAOs to ensure that VOCs do not migrate beyond their current extent and/or increase in magnitude. The corrective measure will reduce concentrations of CVOCs in the groundwater and prevent further migration of CVOCs in the groundwater offsite.

8.3.2.2. Achievement of Corrective Action Objectives

This corrective measure will achieve the CAOs by continuing to degrade PCE and TCE through natural attenuation processes to non-toxic byproducts (i.e., carbon dioxide and ethene), ultimately reducing both the concentration and mass of the contaminants in the groundwater.

8.3.2.3. Source Remediation

Limited source remediation (to the extent practicable and feasible) was accomplished through the implementation of the permanganate corrective measures. However, the bedrock matrix will continue to act as source of contamination to the bedrock groundwater. The monitored natural attenuation remedy will further remediate the source by degrading CVOCs as they back-diffuse to the groundwater from the bedrock matrix.

8.3.3. Comparison to Evaluation Criteria

8.3.3.1. Long-term Effectiveness

The corrective measure will be effective over the long term in that CVOC source concentrations will be reduced, thereby reducing the concentration of CVOCs in the groundwater over the long-term

8.3.3.2. Reduction of Toxicity, Mobility, and Volume

The corrective measure will reduce the toxicity, mobility, and volume of the CVOCs in the bedrock aquifer by reducing the CVOC mass in the shale bedrock matrix and, subsequently, in the bedrock groundwater.

8.3.3.3. Short-term Effectiveness

The corrective measure will have limited effectiveness in the short-term, but will be able to document any changes in groundwater conditions.

8.3.3.4. Implementability

Long-term monitoring is already underway.

9. Summary of Solid Waste Management Units and Corrective Actions

A summary of corrective measures and current status of each SWMU within the Main Manufacturing Area is provided below.

9.1. SWMU No. 1: Surface Impoundment and Sludge Drying Beds

The sludge drying bed that was converted to an emergency holding tank for the storage of liquid waste was formally closed in October 1987. However, due to changes in the closure rules, additional soil removal was necessary for clean closure to be obtained. Soil was removed in January 1994 and the bed was closed clean. A Clean Closure letter was issued for SWMU No. 1 by the NYSDEC in May 1994. No further action is required for this SWMU.

9.2. SWMU No. 4: Demolished Cyanide Treatment Facility

All treatment tanks and waste transfer lines associated with the cyanide treatment facility, formerly located in Building 110A, were above ground and no known releases were ever documented. In 1981, the cyanide treatment operations were relocated to the wastewater treatment plant and the cyanide treatment facility was demolished during the Renovation of Armament Manufacturing (REARM) project. All of the building materials and cyanide treatment units were shipped to a hazardous waste disposal facility and through the monitoring of wells and soil borings, this SWMU was identified as not being a source of cyanide contamination in this area. No further action is required for this SWMU.

9.3. SWMU No. 5: Building 25

A self-contained vapor degreaser unit located in the southeast quadrant of Building 25 was used between 1970 and 1982 for cleaning small metal components in Building 25 with PCE, TCE, and 1,1,1-TCA. CVOCs, including PCE, TCE, and 1,1,1-TCA have been discovered in downgradient monitoring wells. During a Pilot Study in 2004 (Section 4.0), corrective measures for the groundwater at Building 25 were conducted in this area. No further action, other than natural attenuation documented through long-term groundwater monitoring, is required for this SWMU.

9.4. SWMU No. 6: Wastewater Treatment Plant

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 at Building 36 (treatment facility). Remedial actions included soil removal and the installment of a 12,000 gallon waste soluble oil UST to replace the leaking transfer line. Soil and groundwater samples collected did not show elevated levels of heavy metals. However, an extensive groundwater monitoring program is in place for the facility. No further action is required for this SWMU.

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

Eight USTs were reportedly used to store hydraulic oil, lubricants, non-chlorinated degreasing solvents, chlorinated solvents, and skim oil, which were all 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 SWMU Nos. 11 and 12 were leaking upon removal, but no significant residual contamination remained after removal. No further action, other than standard NYSDEC UST monitoring and reporting, is required for these SWMUs.

9.6. SWMU Nos. 15 – 17: Underground Waste Oil Storage Tanks

- SWMU No. 15 – A leaking 1,000-gallon UST located east of Building 15 was removed and replaced in 1995. Based on the results of the soil, sediment, and groundwater/accumulated rainwater samples collected at the pit, the WVA deemed the excavated pit satisfactorily clean. The site was closed clean by the NYSDEC in February 1995.
- SWMU No. 16 – A 1,000 gallon UST located in the west central portion of Building 35 was removed and replaced in 1994. The excavated pit was backfilled with clean sand once the tank was replaced.
- SWMU No. 17 – The line and tank of a 5,000 gallon UST located east of Building 36 was certified as being free of any leaks based upon two tightness tests conducted on January 10, 1995 and February 22, 1996.

No further action, other than standard NYSDEC UST monitoring and reporting, is required for these SWMUs.

9.7. SWMU No. 19: Outfall No. 003

Outfall 003 is the main outfall to the Hudson River, which includes the effluent from the IWTP that flows through outfall 002. Prior to 1970, waste was discharged directly to the Hudson River via this outfall. No leaks or breaks in the pipe have been documented and it is considered unlikely that any traces of hazardous material remains in this outfall. No further action, other than the required monitoring under the WVA NYSDEC SPDES permit, is required for this SWMU.

9.8. SWMU No. 20: Industrial Sewers

The acid, soluble, and cyanide sewers in the MMA were installed in the 1970s. In 1992, 23 defects were noted and repaired in the Manhole 34D chromic acid line as well as the line was re-sleeved. In May 1993, a number of potential leaking points were detected on the chrome acid rinse water line that conveys the waste to the onsite treatment building (Building 36). The spill was reported to the NYSDEC, which resulted in the issuance of a consent order. During the RFI, extensive line repair, soil removal, and groundwater extraction and monitoring were performed. Heavy metals, PAHs, and cyanide were not detected in the groundwater. No further action, other than groundwater monitoring through the long-term monitoring program is required for this SWMU.

9.9. SWMU No. 21: Building 132 Incinerator

The Building 132 incinerator disposed of non-hazardous waste, primarily consisting of waste paper and office trash from 1945 to 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 great than guidance levels, no further action is required for this SWMU.

9.10. SWMU No. 25: Erie Canal

The Erie Canal, located in the eastern portion of the MMA, provided transportation, power, and water for fire protection for the WVA until the canal was relocated to Waterford in 1922 and eventually filled in with dirt, bricks, portions of the canal, and other unknown fill materials in 1940. 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.

9.11. SWMU No. 26: Building 35 Process Pit

During the late 1980s, the West Pit in Building 35, or the Heat Treat and Metal Processing Building, was converted from being used for chrome plating guns and equipment to a furnace pit for heat treatment of cannon tubes. In 1987, POLs were observed to be seeping through cracks in the concrete walls and accumulating in the furnace pit. 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. However, 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.

9.12. SWMU No. 27: Building 135 Process Pit

A High Bay section located at the south end of Building 135 that rises approximately 50 feet above the rest of Building 135 contains three pits known as the Cold Works Pit, Furnace Pit, and Shrink Pit to WVA personnel. 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. LNAPL, which is present in the Blue Lagoon, is most likely from POLs leaking from the machinery in Building 135 may be collecting in a preexisting bedrock depression that gradually migrates towards, and eventually drains into the Shrink Pit, located at the southern end of the depression. Based upon groundwater and soil results, contamination at concentrations greater than guidance levels is not present in this area. No further action is required for this SWMU.

9.13. SWMU: 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. Based on the results of the RFI, no further action is required for the vapor degreaser units at Buildings 20, 110, 120, and 130 under this SWMU. The corrective measures for the vapor degreasers in Buildings 25 and 40 are presented in Sections 5 through 8.

9.14. Chip Handling Facility Areas

Two chip handling facilities, the Building 132 South Chip Handling Area and the Building 123 Chip Handling Area (area surrounded by Buildings 121, 122, and 123) were designated as an additional SWMU. The exact dates of operation for both chip handling facilities is unknown, however, the chip handling facilities at Building 132 and Building 123 were believed to be operational in the mid to late 1950s and between the 1950s and 1960s, respectively. Various investigations were conducted in the areas to assess the soil and groundwater contamination due to the chip handling facilities as well as an 8,000-gallon fuel oil release near Building 121. Soil in the Building 132 area that was found to be contaminated with total petroleum hydrocarbons was excavated, removed, and disposed of at a nearby landfill in 1994. The processes occurring at Building 121, the diesel oil spill (8,000 gallon release) at Building 116, and the Building 123 Chip Handling Facility, are all potential sources of contamination in this area. Two interceptor trenches were installed around Building 121 in 1975 and 1976 to limit free phase product migration and collect and dispose of the free phase product that was observed in wells, piezometers, and test pits in this area. No further action is required for this SWMU.

9.15. Chrome Plating Pit Areas

The Chrome Plating Areas are located in Building 35 and, formerly, in Building 110. 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.

- **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.
- **Building 110 LC Plating Area**: This pit was permanently abandoned in 2009 by backfilling with flowable fill.

Based on the results of the RFI, no further actions are required for this SWMU.

9.16. Chrome Plating Scrubbers

The scrubbers are located at Building 35 (two) and Building 114 (one used for laboratory testing only), and are all still in operation to some extent. The water used to remove contaminants is automatically discharged to the wastewater treatment plant. No previous investigations have been completed for these scrubber areas. No further action is required for this SWMU.

9.17. Vapor Intrusion

Although not designated as a SWMU during the RFI, vapor intrusion was added to the WVA corrective measures program based on new requirements from the NYSDEC and NYSDOH. As discussed herein, the final corrective measures for the buildings impacted by vapor intrusion are subsurface depressurization systems and indoor air filtration (Building 40 only).

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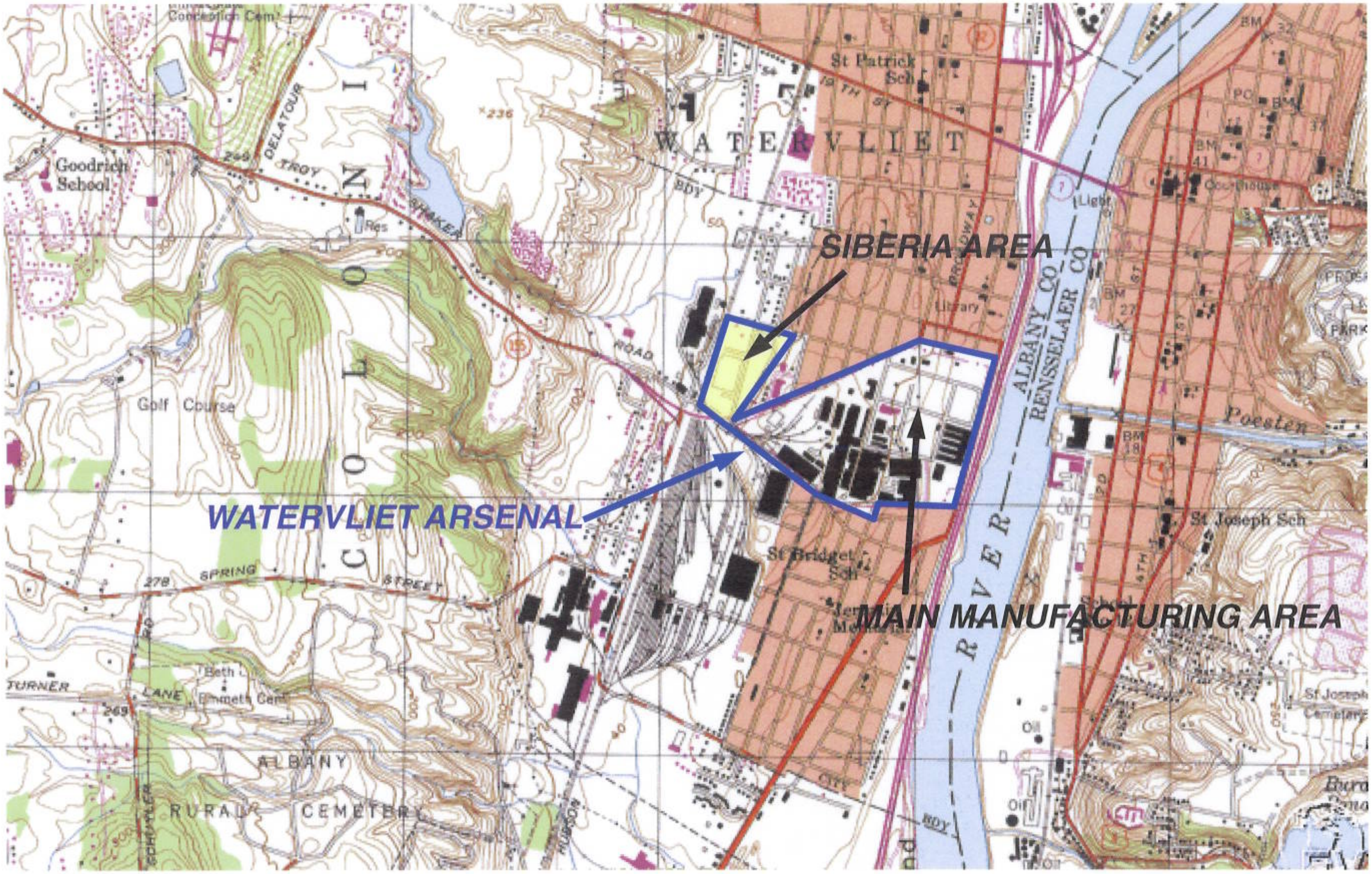


SOURCE: U.S.G.S 7.5 MIN. TROY SOUTH QUADRANGLE

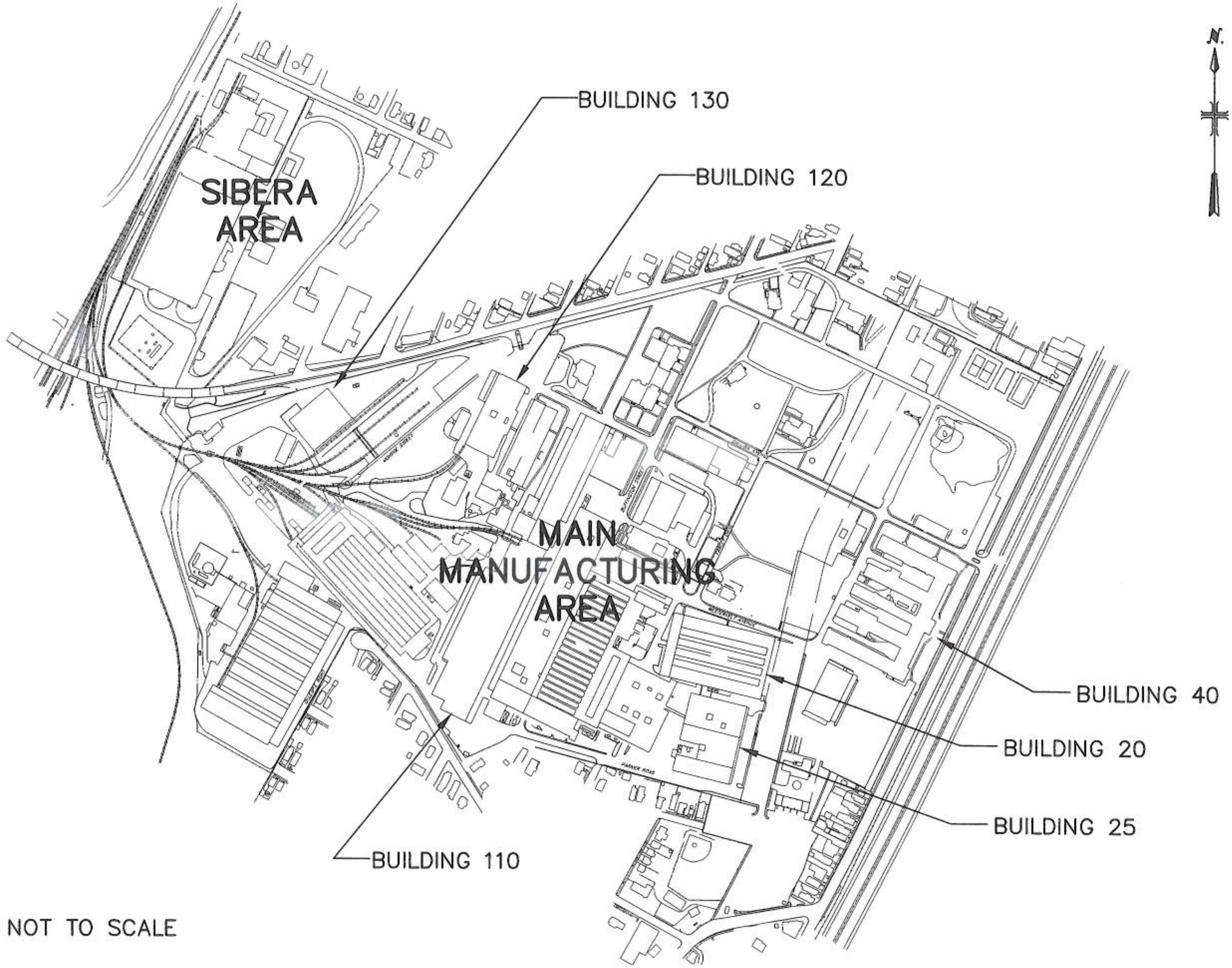
SCALE IN FEET
0 1000 2000 4000

US Army Corps of Engineers
Baltimore District

CORRECTIVE MEASURES STUDY
MAIN MANUFACTURING AREA, WATERVLIET ARSENAL,WATERVLIET, NEW YORK

SITE LOCATION

FIGURE 1-1



NOT TO SCALE

MALCOLM PIRNIE CORRECTIVE MEASURES STUDY MAIN MANUFACTURING AREA WATERVLIET ARSENAL, WATERVLIET, NEW YORK	SITE MAP	MALCOLM PIRNIE, INC. FIGURE 1–2