MALCOLM PIRNIE

DRAFT CORRECTIVE MEASURES STUDY (CMS) PRELIMINARY SCREENING REPORT WATERVLIET ARSENAL, SIBERIA AREA

Watervliet, New York

US Army Corps of Engineers
Baltimore District

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1.0 INTRODUCTION

Malcolm Pirnie, Inc. (Malcolm Pirnie) has conducted a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) at the Siberia Area of the Watervliet Arsenal (WVA), Watervliet, New York. The RFI was performed under contract with the U.S. Army Corps of Engineers (USACE), Baltimore District in accordance with an Administrative Order on Consent between WVA, the New York State Department of Environmental Conservation (NYSDEC), and the United States Environmental Protection Agency (USEPA). The results of the RFI have been presented in the Final RCRA Facility Investigation Report, Siberia Area, Watervliet Arsenal, Watervliet, New York dated December 1997 (Final RFI Report).

Chlorinated organic compounds, petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and metals were detected in groundwater and or in soil at the Siberia Area as a result of the RFI. A Corrective Measures Study (CMS) has been initiated by Malcolm Pirnie on behalf of the USACE, Baltimore District to evaluate, develop, and recommend Corrective Measure Alternatives for the impacted areas of the Siberia Area. Additional investigations have been completed to define the limits of soil/sediment contamination and the vertical extent of groundwater contamination in the Northeast Quadrant as part of the CMS. These data are included in the CMS Field Data Report, Siberia Area, Watervliet Arsenal, Watervliet, New York dated October, 1998.

Bench scale and pilot scale treatability studies are being conducted to evaluate the applicability and effectiveness of various treatment technologies including a reactive barrier wall technology for remediation of groundwater contaminated by volatile organic compounds and bioremediation for soils contaminated with petroleum hydrocarbons and PAHs. Additional bench and pilot scale treatability studies may be performed to evaluate the effectiveness of other innovative technologies. Interim Corrective Actions (ICAs) may also be performed to remove contaminated soils in limited "hot spots".

An Exposure Assessment, which included the development of site specific target cleanup levels (SSTLs) for the Siberia Area, was also completed as part of the CMS. This Exposure Assessment, as well as state and federal cleanup standards and or guidelines will be used to evaluate corrective measures alternatives for the Siberia Area.

1.1 Purpose of Report

The purpose of this report is to present the results of the preliminary screening of corrective measure technologies identified for the Siberia Area of the Watervliet Arsenal. The preliminary remedial technologies have been identified based on the results of the Final RFI, the additional CMS field investigation, the Exposure Assessment, and preliminary results of bench-scale treatability studies and pilot systems.

1.2 Site Background

The WVA is a 140-acre government-owned installation under the command of the U.S. Army Industrial Operations Command (USAIOC). The WVA is located in the City of Watervliet, New York, which is west of the Hudson River, and 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. Its original purpose was to distribute supplies (i.e., ammunition, harnesses, and gun cartridges) to troops along the northern and western frontiers. The Erie Canal, formerly located in the eastern portion of the main manufacturing area of the WVA, was built between 1817 and 1824 to provide transportation and power, until it was abandoned and relocated to Waterford in 1922. The Canal was filled in with dirt, brick and other fill materials in the early 1940's. The eastern wall of the Canal still remains and forms a portion of the east side of Gibson Street. Over the years, the main function of the WVA changed from the production of small arms ammunition, cannon cartridges, and leather goods, to the production of the nation's first 16-inch gun. The WVA also played a major role in the research and development of cannons, mortars, and recoilless rifles. From 1950 to 1970, the WVA built anti-aircraft weapons, the 90 mm gun for the medium tank, the 152 mm gun launcher, the lightweight 60 mm mortar, and a new 8-inch gun/howitzer for use in the Korean and Vietnam Wars. The WVA is still responsible for the manufacture of large caliber cannons. Benet Labs is also currently located within the WVA allowing for on-site research and development, to prototyping and testing, and full-scale manufacturing.

A large, swampy, 14-acre area located to the west of the main manufacturing area was purchased by WVA in the early 1940's. This area, presently known as the Siberia Area, is shown on Figure 1-2. The Siberia Area was immediately filled in with debris consisting of slag, cinders, wood, brick and any available debris of unknown origin. Once filled in, two areas were used for burning combustible material (i.e., scrap lumber and other sanitary waste) until 1967.

The Delaware and Hudson Railroad is adjacent to the western property line, across which the former Adirondack Steel Casting Co. is located. Residential properties adjoin the property to the north and northeast. Perfection Plating, which formerly manufactured metal plates for brake pads is located along a portion of the eastern property line. Shaker Tire Sales is located along the southeastern property line. Lands owned by the Town of Colonie and formerly owned by the Delaware and Hudson Railroad yard are located along the southern property boundary.

The Siberia Area is used for the interim storage of raw materials, hazardous materials, finished goods, and supplies brought in from the main manufacturing area of the WVA. The handling of these materials may have contributed to groundwater and soil contamination, particularly the handling of metal chips coated with cutting oils; scrap metals which are salvaged; and scrap lumber which is stockpiled until removed from the site. All of the above have either historically been, or are presently, stored directly on the ground surface.

In addition, the WVA has reported that mixtures of oils and solvents removed from underground storage tanks (USTs) were sprayed on the ground for dust control in the Siberia Area. The WVA no longer employs this practice. Elevated levels of chromium and lead have also been detected in the soil and groundwater in the northeastern section of the Siberia Area. This chromium and lead contamination originates from the Perfection Plating Facility located hydraulically and topographically upgradient of the site.

To assist in the descriptions of locations within the Siberia Area, the Siberia Area has been divided into four quadrants: southwest (SW), southeast (SE), northeast (NE) and northwest (NW) (Figure 1-3). Located in the SW quadrant are the Main Substation and Building 145; the lumber yard is located in the SE Quadrant; former burning pits and

Buildings 148 and 151 are located in the NE Quadrant and the Chip Handling Facility is located in the NW Quadrant. Historic land use and site features are shown in Figure 1-4.

1.3 Generalized Physical Setting

Three unconsolidated deposits are encountered at the Siberia Area. The upper deposit is a fill unit approximately four feet thick. The second deposit is a clayey silt, typically two to six feet thick, which extends to the top of the weathered shale at most locations across the site.

Fluvial deposits are the third unit encountered. This third deposit consists primarily of sand and gravel and is found in what are believed to be abandoned stream/river channels buried beneath the Siberia Area. The largest of these relatively coarse fluvial deposits can be found immediately above the bedrock in the Northwest Quadrant where an abandoned channel has been filled with approximately ten feet of course deposits.

The wetland which formerly occupied the Siberia Area was filled in with a mixture of cinders, sand, brick, wood and concrete when the site was purchased by WVA in the 1940s. This fill typically varies in thickness from two to four feet, averaging approximately 3.5 feet at monitoring well and soil boring locations across the site.

The clayey silt layer is typically found at depths ranging from two to ten feet below the ground surface. This unit is a mottled olive-gray clayey silt containing rust staining and trace roots and other organic material. This continuous clayey silt layer underlies a majority of the site. These sediments were most likely deposited in the wetland that formerly occupied the entire extent of the Siberia Area.

Overburden is generally thickest in the NW Quadrant. The greatest thickness of overburden encountered was 31.4 feet at SB-4. The overburden is shallowest along the eastern boundary of the site where the weathered bedrock is typically found at approximately four feet below the ground surface. Topographically, the Siberia Area is generally flat, with elevations between 38 and 46 feet above mean sea level. Variations in overburden thickness are primarily the result of changes in elevation of the top of bedrock.

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 were noted in the split-spoon samples and the reactive wall trenching activities where bedding planes/parting surfaces were nearly vertical in orientation. During bedrock coring, nearly vertical fractures were often encountered. The lack of mineralization, aside from occasional calcite and pyrite deposited secondarily by groundwater, tends to support the observation that little metamorphism has taken place. However, outcrops in the Main Manufacturing Area show some quartzites and slatey cleavage.

The bedrock generally exhibits three distinct zones based on the degree of weathering. The first is an extremely weathered zone approximately four feet thick. Beneath this extremely weathered bedrock is a zone of less weathered shale showing minimal competentcy overlying competent bedrock with rock quality determinations (RQDs) frequently in the 80 to 90 percent range. Fractures in the competent bedrock were often infilled with clay and showed occasional deposits of calcite and pyrite. These fractures were frequently high angle fractures, often in excess of 45 degrees from horizontal.

The majority of the overburden deposits are saturated and hydraulically well connected with the weathered bedrock. The primary exception is in the NW Quadrant where several monitoring wells are screened in and above a dense clayey silt layer with relatively low permeability. Approximately ten feet of channel deposits underlie this clayey silt unit in the NW quadrant. Wells screened in the channel deposits do not exhibit good hydraulic communication with the wells screened in the clayey silt. Vertical hydraulic head differences of approximately three to eight feet have been observed between these two units during both high and low water table conditions.

During the majority of the year the water table is within the overburden deposits, but during seasonal low water table conditions the water table declines into the weathered bedrock over much of the site. Groundwater levels in the Siberia Area have historically equaled or exceeded ground surface elevations during the snow melt runoff season or high precipitation events. This is consistent with the Siberia Area's former designation as a wetland. The depth to groundwater in the overburden deposits varies from approximately two feet below the ground surface along the westerly edge of the

Northwest Quadrant to approximately six feet below the ground surface along the easterly property line.

Calculated vertical hydraulic gradients in the Siberia Area generally indicate a downward gradient. However, during extreme seasonal low groundwater conditions, the vertical component of groundwater flow appears to reverse, with gradients ranging from –0.07ft/ft (an upward hydraulic gradient) to 0.71 ft/ft (a downward hydraulic gradient) in certain areas of the NE Quadrant. Typically, greater vertical hydraulic gradients are apparent at well clusters in the NW Quadrant. These monitoring well clusters typically show vertical hydraulic gradients in excess of 0.40 ft/ft. Monitoring well clusters in the SW Quadrant near the power substation have much lower vertical hydraulic gradients.

Hydraulic conductivities of the wells screened primarily in the clayey silt ranged from 4.8×10^{-4} cm/sec to 8.1×10^{-5} cm/sec. Hydraulic conductivity of the wells screened primarily in the fill unit ranged from 2.66×10^{-2} cm/sec to 1.49×10^{-4} cm/sec. The well screened in a fluvial sand and gravel deposit beneath the clayey silt had a calculated hydraulic conductivity of 1.31×10^{-3} cm/sec.

Groundwater flow in the fill and clayey silt across the Siberia Area is generally southeast to northwest from the groundwater divide that runs roughly north-south through the manufacturing portion of the Arsenal. However, due to the installation of the sewer lines that run between the NW and NE Quadrants of the Siberia Area, it appears that the groundwater in these two quadrants drains into the sewer lines and into disturbed materials surrounding the sewer lines and then potentially migrates off the site to the north. Groundwater migrating northward in the NE Quadrant may be intercepted by the sanitary sewer line running east-west between the looping roadway in the NE Quadrant and the northern fence line. A groundwater divide appears during seasonal high and low water table conditions, running approximately northwest/southeast through 95MPI-MW-20. Groundwater to the north of this divide is most likely to enter the sewer line and disturbed material and be discharged northward from the site. Groundwater to the south of this divide tends to flow westward off the site.

The groundwater flow within the competent bedrock occurs primarily along fractures, with little or no flow within the primary porosity of the bedrock. The piezometric surface of the bedrock is typically five to eight feet below the ground surface. Groundwater flow in the bedrock is generally northeasterly in the SW Quadrant, northwesterly in the lumber yard in the SE Quadrant, and westerly across the remainder of the eastern portion of the Siberia Area. The horizontal gradient of groundwater flow in the bedrock is significantly shallower in the western portion of the Siberia Area than in the eastern portion. Hydraulic conductivity testing results at bedrock monitoring wells in the manufacturing area typically ranged from 10^{-3} cm/sec to 10^{-5} cm/sec.

2.0 DESCRIPTION OF CURRENT SITUATION

2.1 Nature and Extent of Contamination

The following summary of the nature and extent of contamination at the Siberia Area is based on the data obtained from the sampling events conducted by Malcolm Pirnie as presented in the Final RFI and the CMS Field Data Report, as well as historical data obtained during previous investigations (CTM, 1986; GTI, 1987; EA, 1988; ESE 1990; IMS, 1994; E&E, 1994 and 1995). Samples collected by Malcolm Pirnie include surface soil, subsurface soil, groundwater field screening (Geoprobe), groundwater, surface water and sediment, sewer water and sediment, and sewer bedding groundwater samples. Specific areas of concern will be identified in subsequent sections of this report after a discussion of site specific action levels.

2.1.1 Soils

Soil contamination has been detected throughout the Siberia Area as well as along the perimeter of the NE and NW Quadrants outside of the Siberia Area fence. As a point of reference, values published in the NYSDEC Technical Administrative Guidance Memorandum (TAGM) HWR-94-4046 Determination of Soil Cleanup Levels, revised January 24, 1994, have been compared with the analytical results for the soil samples. The TAGM values are conservative guidance values and will be compared in subsequent sections to Site Specific Target Levels (SSTLs) developed in the Exposure Assessment. In general, organic contamination in the soils is primarily limited to the presence of PAHs, as concentrations of VOCs, pesticides, and PCBs were mostly below TAGM values. Chromium, lead, and arsenic are the primary inorganic contaminants of concern in the soil.

Observations made during the RFI field activities documented the presence of petroleum contamination in the soils in all four quadrants. The most apparent areas of contamination based on visual and olfactory observations include: the Main Substation area in the SW Quadrant, the Chip Handling Facility in the NW Quadrant, in an area around monitoring well 95MPI-MW-32 in the NE Quadrant, and SB-22, SB-23, 95MPI-MW-26 and 95MPI-MW-35 in the SE Quadrant. The soil boring locations and monitoring well locations are presented in Figures 2-1 and 2-2, respectively. Slight to strong petroleum odors were noted in each of these areas. Petroleum saturated soils were observed in the soils collected from 95MPI-MW-32 (0-10 feet), 95MPI-MW-29 (0-7.5 feet), SB-4 (0-6 feet), SB-6 (0-4 feet), SB32-E (4-8 feet), and SB32-5 (4-6 feet).

Some of the previous investigations analyzed subsurface soil samples for total petroleum hydrocarbons (TPH) via SW 846 Method 418.1. These compounds were detected in the subsurface soils throughout the site, but were generally the highest in the NE and SE Quadrants. However, the maximum TPH concentrations (44,400 μg/g to 112,000 μg/g) were detected adjacent to the Main Sub Station in the SW Quadrant near 95MPI-MW-29, which contained petroleum-saturated soils, as well as the maximum concentration of total semi-volatiles for the shallow and subsurface soil samples. A high TPH concentration (21,900 μg/g) was also detected in the NE Quadrant at a depth of approximately six feet bgs. This boring was drilled in the vicinity of the petroleum-saturated soils encountered at 95MPI-MW-32. Elevated TPH concentrations relative to the site-wide samples were detected in the area between Building 148 and the lumber yard. Two of the samples in this area collected from a depth of approximately four feet bgs contained 16,000 μg/g and 7,880 μg/g of TPH.

The concentrations of several of the potentially carcinogenic PAHs, including benzo(a)pyrene, benzo(a)anthracene, and dibenzo(a,h)anthracene, were detected in the surface, shallow, and subsurface soils above TAGM values, especially in the areas described above where field observations noted the presence of petroleum contamination. PAH contamination in the soil extends to the eastern, northern, and western fence lines. As outlined in the RFI Report, the concentrations of total semi-volatile compounds, as well as the concentrations of the of total PAHs, carcinogenic PAHs, and individual semi-volatile compounds (benzo(a)pyrene) in the soils decrease with increasing depth. PCBs do not appear to be a problem in the soils in the Siberia Area, as only two surface soil samples contained PCB concentrations in exceedance of the 1 part per million TAGM value. Heptachlor epoxide was the only pesticide detected above TAGM values in the soil, and was only detected in samples from two soil borings in the NW Quadrant. Two isolated areas in the NE and NW Quadrants indicate VOC contamination in the soils. The former burn pit area in the NE Quadrant contained chlorinated VOCs above TAGM values in the surface and subsurface soil. A subsurface soil sample collected along the northern fence line in the NW Quadrant contained methylene chloride, 2-butanone, and cis-1,3-dichloropropene.

Inorganic contamination in the soils is the most prevalent in the NE and SW Quadrants. Chromium is the most extensive and widespread inorganic with the maximum concentrations detected in the NE and SW (Main Substation area) Quadrants. Lead contamination in the soils is the most extensive along the eastern fence line and Main Substation area. Lead concentrations in the NE Quadrant show a decrease with increasing distance (heading west) from the eastern fence line. Arsenic contamination is widespread, though the maximum concentrations in the surface and shallow soils were almost exclusively located along the eastern, northern, and western fence lines. Chromium, lead, and arsenic concentrations in the soils generally decrease with increasing depth.

2.1.2 Groundwater

As a point of reference, the federal and New York State groundwater standards have been compared with the existing analytical results for the groundwater samples collected from the Siberia Area. These standards include the USEPA Maximum Contaminant Levels (MCLs), the NYS Class GA Drinking Water Standards, and the NYS MCLs. These are conservative values and will be compared in subsequent sections of this report to the groundwater SSTLs developed in the Exposure Assessment.

ESE (1991) conducted TPH analyses of groundwater samples prior to the RFI field investigation. Five monitoring well samples, all collected from bedrock wells, contained TPH concentrations above the detection limit of 200 µg/l. The TPH concentrations were determined using SW 846 Method 418.1. Four of these five wells were located in the southern quadrants (SE and SW), with the maximum TPH concentration of 500 µg/l detected in MW-GTI-3 in front of Building No. 148. Petroleum hydrocarbon contamination was also detected in the SW and SE Quadrants during a groundwater field screening survey conducted prior to placement of the RFI monitoring wells. The concentration of petroleum hydrocarbons was determined with a gas chromatograph/flame ionization detector (GC/FID). The concentrations were calculated using the sum of the areas of all chromatogram peaks. Concentrations of total volatile organic compounds (VOCs) up to 20,600 µg/l with GC signatures indicative of diesel fuel and kerosene were encountered in the vicinity of the Main

Substation in the SW Quadrant. A total VOC concentration of 18,600 µg/l with a kerosene signature was encountered in the SE Quadrant north of the lumberyard area where elevated concentrations of TPH in soils were also encountered. Figure 2-3 presents the total VOC results from the screening sampling. Although these screening data were used to guide the placement of additional monitoring wells, the off-site laboratory data did not confirm the elevated concentrations of organic compounds. However, field observations made during the RFI monitoring well development activities documented the presence of a petroleum sheen on the development water from 95MPI-MW-31 in the SW Quadrant and 95MPI-MW-35 in the SE Quadrant. Furthermore, a petroleum odor was documented during the development of 95MPI-MW-36 and 37.

Based solely on the two rounds of groundwater samples collected during the RFI and additional samples collected during the CMS from the permanent monitoring wells in the Siberia Area, groundwater contamination is primarily limited to the NE Quadrant. Exceedances of NYSDEC Class GA Standards for chlorinated VOCs were noted in overburden, hybrid (screened in overburden and bedrock), and bedrock wells during each sampling event. Although several semi-volatile compounds were reported as exceeding DEC Class GA Standards, the high concentrations of semi-volatile organic compounds (PAHs) detected in the shallow and subsurface soils immediately above and at the water table were generally not detected in the groundwater samples.

The first round groundwater sampling event was performed during the seasonal low water table conditions. The only semi-volatile compound detected above applicable standards (except for bis 2-ethylhexyl phthalate, which is not considered a site contaminant), was benzo(a)anthracene in 95MPI-MW-26. This monitoring well is located on the hydraulically upgradient property boundary in the SE Quadrant, which may indicate an upgradient source of benzo(a)anthracene contamination.

The second round of groundwater sampling was performed during seasonal high water table conditions. The second round sample concentrations for individual semi-volatile compounds exceeded applicable standards at seven groundwater sampling locations in the Siberia Area. All of these were in the NE Quadrant with the exception of 95MPI-MW-35, a monitoring well along the northern boundary of the SE Quadrant.

Benzo(a)anthracene concentrations exceeded applicable standards in five of the seven locations. Detected concentrations of benzo(a)anthracene ranged from 0.08 µg/l (MW-EA-5) to 0.2 µg/l (95MPI-MW-35, and MW-EA-8). Two exceedances were noted in bedrock wells, two in overburden wells, and one in a hybrid well.

Detectable concentrations of chrysene, benzo(a)pyrene, and naphthalene were reported in second round groundwater samples although they were not detected in first round samples. Chrysene appeared in six of the seven wells which exceeded applicable standards for at least one semi-volatile compound. The reported concentrations of chrysene ranged from 0.1 µg/l (95MPI-MW-34, MW-DEC-2, and MW-DEC-3) to 0.2 µg/l (95MPI-MW-23RE, 95MPI-MW-35, MW-EA-8). Benzo(a)pyrene was detected in 95MPI-MW-35, MW-DEC-3, and MW-EA-8 at 0.1 µg/l. Naphthalene was detected in one well above the NYSDEC Class GA standard, at 16 µg/l in 95MPI-MW-32. Reported concentrations for these compounds were detected in exceedance of the New York State Class GA Standard in wells of overburden, bedrock, weathered bedrock and hybrid construction.

A micro-well, 98MPI-MW-40, was installed in the Main Substation area during the CMS to further investigate the impact of the petroleum-contaminated fill on the groundwater. With the exception of an estimated 1 µg/l of tetrachloroethene, no detectable concentrations of VOCs or diesel range organic compounds were detected from the groundwater sample collected from 98MPI-MW-40.

Figure 2-4 shows the estimated extent of chlorinated organics detected in the shallow groundwater based on samples collected during the groundwater field screening survey and monitoring well sampling. The organic contamination in the NE Quadrant appears to migrate along the groundwater flow path toward the sewer lines.

Based on visual observations of the sewer lines during test pitting operations, it is apparent that the storm sewer piping in the NE Quadrant is acting as a line sink for groundwater. Although there may be a component of groundwater flow and solute transport around the storm sewer pipe (i.e., in the disturbed material), the majority of flow is into the pipe through bell joints that are not mortared and are damaged.

Two additional monitoring wells (97MPI-MW-39 and 98MPI-MW-41) were installed as part of the CMS to further delineate the extent of VOC contamination in the NE Quadrant. Groundwater samples collected from monitoring wells 95MPI-MW-32 and

97MPI-MW-39 confirmed the presence of VOC contaminated groundwater in the overburden and fractured bedrock units at this location. Groundwater samples collected at various discrete vertical intervals during the installation of bedrock well 98MPI-MW-41 confirmed the presence of contaminated groundwater in the bedrock. Concentrations of total VOCs decreased with depth from 4,704 µg/l (at 14 to 34 feet bgs), 2,710 µg/l (at 34 to 54 feet bgs), and 51 µg/l (at 74 to 94 feet bgs). Based on these chemical analytical data and the location of 98MPI-MW-41 within what is believed to be the source area, it is reasonable to assume that the vertical extent of VOC contamination has been established. The areal extent of contamination within the bedrock can be estimated by the analytical results from groundwater samples obtained from wells located hydraulically upgradient, cross gradient, and down gradient from 98MPI-MW-41. VOCs were not detected above NYSDEC Class GA Standards in the groundwater samples collected from the downgradient bedrock wells 95MPI-MW-30 and 95MPI-MW-34 or from cross-gradient and upgradient bedrock wells MW-GTI-3, MW-ESE-9, and 95MPI-MW-23.

Groundwater samples containing chromium concentrations exceeding NYSDEC Class GA Standards were collected from wells in the NE Quadrant screened within all stratigraphic units (overburden, weathered bedrock, and bedrock). The samples collected from the monitoring wells directly downgradient from Perfection Plating (MW-EA-7, MW-EA-8, and MW-ESE-9) contained hexavalent chromium concentrations in both the filtered and unfiltered samples. The elevated chromium concentrations are most likely related to the Perfection Plating facility, at which a groundwater extraction system is now in operation.

Lead and arsenic were also detected above NYSDEC Class GA standards in several groundwater samples, but only in the unfiltered samples. Barium is believed to be indigenous to the bedrock groundwater, and is not considered a site contaminant.

2.1.3 Off-Site Surface Water, Soil and Sediment

During the RFI, one surface water and one sediment sample were collected from outside of the NW fence line to assess whether contamination from the Siberia Area has affected this area. Additional soil and sediment sampling was completed during the CMS field activities to further assess the impacts of the Siberia Area contamination on the surrounding area. Three surface soil samples were collected from just outside boundaries of the NW and NE Quadrants. Four sediment samples were collected in the ditch located immediately north of the northern fence line and six sediment samples were collected from the drainage ditch located west of the NW Quadrant. For comparison, the compound concentrations in the surface water sample were compared to NYSDEC Class C standards and the sediment concentrations were compared to the TAGM values applied to the surface soil samples. Consistent with the nature of the contamination in the Siberia Area, concentrations of PAHs and inorganic analytes were detected above TAGM values in the surface soil and sediment samples. It should be noted that the PAH concentrations from the surface soil and sediment samples collected adjacent to the northwest corner of the site may be biased high as they were collected in areas of petroleum staining and next to railroad bedding (i.e., potential contamination not related to site activities).

Surface water sample SW-1 contained low (less than 0.005 μg/l) concentrations of pesticides above the Class C standards of 0.001 μg/l. This aqueous sample was non-detect for all VOCs, and contained low concentrations of SVOCs (approximately 11 μg/l total). Only bis 2-ethylhexyl phthalate, which is not considered a site contaminant, was detected above Class C standards. Surface water sample SW-1 (unfiltered) contained concentrations of lead (26.5 μg/l) and selenium (2.6B μg/l) above Class C standards

2.2 Treatability Studies and Interim Corrective Actions

Bench scale and pilot scale treatability studies are currently being conducted to evaluate the applicability and effectiveness of various remedial technologies for soil and groundwater contamination at the Siberia Area. Additional treatability studies may also be performed to evaluate the effectiveness of additional technologies and combinations of technologies. Interim Corrective Actions (ICAs) may be performed to remove contaminant source areas.

2.2.1 Implemented Treatability Studies

2.2.1.1 Soils

Bench-scale laboratory biotreatability studies are underway to determine the effectiveness of in-situ bioremediation as a corrective measure for petroleum contaminated soils in the Siberia Area. There are four objectives for the laboratory biotreatability studies:

(1) Demonstration of the ability of indigenous microorganisms to biodegrade PAHs under aerobic and anaerobic conditions;

(2) Determination of the optimal rate of PAH and petroleum hydrocarbon degradation through bioslurry experiments;

(3) Demonstration of biodegradation of PAHs and TPH by a reduction in concentration of total PAHs of greater than 50% and TPH greater than 75% in bioslurries;

(4) Demonstration of biodegradation of PAHs and TPH by a reduction in concentration of total PAHs of greater than 50% and TPH greater than 75% in pan studies and;

(5) Demonstration of toxicity associated with contaminated soils before and after biotreatment by performing an earthworm toxicity study.

The results of the bench-scale biodegradation studies under simulated field conditions will be evaluated to determine the best options for pilot-scale and full scale bioremediation at the site.

2.2.1.2 Groundwater

A bench-scale laboratory treatability study has been completed to determine the effectiveness of permeable barrier technology with a zero valent iron reactive medium for the groundwater contaminated with chlorinated hydrocarbons in the NE Quadrant. The results of the bench-scale study showed that an iron reactive wall system would effectively treat the groundwater. A pilot-scale treatability system was subsequently designed using the results of the bench-scale study.

A permeable barrier wall pilot treatment system utilizing zero valent iron as a reactive medium was installed in November 1998. The pilot treatment system consists of two separate reactive walls that intercept the overburden and weathered bedrock VOC plume as defined in the RFI. An extensive groundwater monitoring well network was also installed hydraulically upgradient, within, and downgradient of each wall segment. Groundwater samples will be collected from the monitoring wells and analyzed for VOCs as well as inorganic parameters as part of the long-term monitoring plan for the Watervliet Arsenal. These data will be used to evaluate the effectiveness of the pilot-scale treatment system with respect to remediating the VOCs as they pass through the walls as well as gauging the amount of mineral precipitation within the reactive zone.

2.2.2 Potential Additional Treatability Studies

Additional bench-scale treatability studies may be performed to further evaluate whether bioremediation is a viable and cost-effective remedial option for the contaminated media at the Siberia Area. These studies will expand upon the on-going biotreatability studies by evaluating 1) the ability of indigenous microorganisms to biodegrade TPH in groundwater; and 2) the potential for use of active bioremediation followed by natural attenuation for TPH and PAH impacted soils.

The bench-scale groundwater biotreatability evaluation may be conducted to determine the potential for in-situ treatment of petroleum hydrocarbons present in the groundwater. The results of this work will be used to evaluate whether biosparging is a viable treatment option. Biosparging is a process whereby air is delivered to the vadose zone and/or saturated zone to promote aerobic biodegradation of organic contaminants.

The use of in-situ active bioremediation to rapidly reduce the more soluble, more leachable, and potentially more mobile contaminants followed by natural attenuation may also be evaluated in a bench-scale study. The organics remaining after the first stage of active bioremediation are retained in place and are biodegraded as they become available through slow desorption from soil particles. The rate of desorption should not exceed the rate of intrinsic biodegradation. Depending on the site-specific action levels developed, it may be more cost-effective and technically feasible to implement this combination of active followed by intrinsic bioremediation rather than attempt to reduce contaminant concentrations below levels at which organic compounds are "bioavailable".

2.2.3 Interim Corrective Actions

The source of the chlorinated VOC groundwater contamination in the NE Quadrant is believed to be related to the former burn pit area located in the immediate vicinity of the elevated groundwater concentrations detected in 95MPI-MW-32. The contaminated soils of the burn pit were encountered during soil excavation activities associated with the collection the bench-scale treatability soil samples. After further delineation, the contaminated soil may be excavated and disposed of off site as an Interim Corrective Action.

3.0 ESTABLISHMENT OF CORRECTIVE ACTION OBJECTIVES

Corrective action objectives are established to assess and guide the extent of remediation required and to ensure that the contaminated media are cleaned up to appropriate levels that are protective of human health and the environment. Site specific corrective action objectives have been established for the on-site contaminated surface soil, subsurface soil, groundwater, and off-site surface soil and sediment at the Siberia Area. These objectives are based on the results of the RFI Report, the SSTLs identified in the Exposure Assessment, and applicable NYSDEC and USEPA standards and guidance criteria.

3.1 Soil Corrective Action Objectives

The applicable New York State soil guidance criteria that the analytical data were initially compared to are the NYSDEC Technical Administrative Guidance Memorandum (TAGM) HWR-94-4046 Determination of Soil Cleanup Levels, revised January 24, 1994. The TAGM values are conservative guidance values, meant to be protective of human health and the environment under the most conservative exposure scenarios. The TAGM values for many of the organic compounds have been derived using the water/soil partition theory for protection of groundwater quality. As outlined in TAGM 4046, these values can be adjusted based on the site-specific carbon content of the soils. The exceptions are the TAGM values for semi-volatile compounds that are based on the USEPA Health-Based Criteria (i.e., carcinogenic PAHs) or the generic criteria for individual semi-volatile compounds (50 mg/kg). These TAGM values are not adjusted for total organic carbon (TOC) content. Published TAGM guidance values for organic compounds other than PCBs are based on a soil TOC content of one percent. PCB guidance values are based on a TOC of five percent.

3.1.1 TAGM Cleanup Levels

The average TOC value, as determined in the RFI, for the fill material in the Siberia Area is eight percent and is one percent for native soils. These TOC values were used as correction factors to establish most of the site-specific TAGM values for soil samples in each strata. A correction factor of eight was applied to organic compounds in fill soils with the exception of PCBs and the semi-volatile compounds (PAHs) discussed above. Since the uncorrected TAGM value for PCBs is based on a TOC of five percent, the TAGM values for PCBs in fill soils were multiplied by a correction factor of 1.6 (eight percent divided by five percent). For native soils, a correction factor of 0.2 was applied to PCB TAGM values (one percent divided by five percent). Each soil sample is compared to these adjusted TAGM values based on its designation as either a fill sample or a native soil sample. In addition to the TAGM values derived for individual compounds, soil cleanup criteria for odor are also outlined in TAGM 4046. Any time a soil exhibits a discernable nuisance odor, it shall not be considered clean, even if it has met the numerical criteria.

TAGM values for inorganics are not based on TOC values. The TAGM values for most of the inorganic analytes are based on site background concentrations. The average concentrations of inorganic compounds in four surface soil samples obtained from a "clean" area of the Arsenal where no previous manufacturing has occurred were designated as site background samples.

3.1.2 Site Specific Target Levels

The TAGM values have been used for comparison of the data and are not proposed cleanup objectives/action levels. Risk-based, site specific target levels (SSTLs) have been developed based on the potential human exposure scenarios that may exist currently and/or in the future at the Siberia Area. The environmental parameters, chemical-specific parameters, exposure parameters, and toxicological criteria used to derive the SSTLs are outlined in the Exposure Assessment. The specific analytes for which SSTLs were developed in the Exposure Assessment were chosen based on their frequency of detection within a given medium (i.e., five percent frequency of detection for a data set of at least 20) and not necessarily based on elevated concentrations. Various exposure scenarios were evaluated including Arsenal and utility worker exposure on-site and resident adult and child exposure off-site resulting in various SSTLs for a given compound. The lowest SSTL from among those derived is presented in Table 3-1. The USEPA revised interim guidance value for lead in soil at residential properties (USEPA, 1998, 1994) is included in Table 3-1 as an SSTL. The on-site surface soil referenced in the Exposure Assessment includes the surface soil samples collected on-site as well as the shallow (0 to 2 feet bgs) sample intervals from the soil borings and monitoring well installations.

Also included in Table 3-1 are site-specific soil saturation concentrations (calculated in the Exposure Assessment) for each organic chemical of potential concern in soil, and site-specific inorganic chemical concentrations in background soil. The soil saturation concentrations are included for comparison purposes since, for some organic chemicals of potential concern in soil, the derivation of the SSTLs results in values that are greater than these physicochemical limits. These SSTLs are replaced in Table 3-1 with the notation that they are greater than the respective physicochemical limit. Two of the SSTLs for arsenic in soil are less than the average site-specific background concentration; they are replaced in Table 3-1 with the notation that they are less than background.

The only hexavalent chromium contamination in soil or groundwater at the Siberia Area is related to the Perfection Plating site and is being addressed under the remedial activities for that site. Hexavalent chromium was not detected in groundwater collected from elsewhere at the Siberia Area during the RFI. Thus, the SSTLs for chromium in soil and groundwater for elsewhere at the Siberia Area are based on trivalent chromium.

3.1.3 Proposed Corrective Action Objectives for Soil

The individual compounds and analytes for which exceedances above the TAGM concentrations were detected in soil samples have been selected as contaminants of concern for further evaluation in the Corrective Measures Study. Proposed cleanup objectives have been developed for these contaminants of concern for the evaluation of potential corrective measures. As summarized in Section 2.1.1, the exceedances in the on-site soil generally include VOCs detected in the NE quadrant as well as carcinogenic PAHs, arsenic, chromium, and lead detected at elevated concentrations in all four quadrants. TAGMs, adjusted TAGMs, and SSTLs will be evaluated for determining the site specific corrective action objectives for the impacted soils in the Siberia Area. As an example, based solely on the empirically derived SSTLs, soil saturated with petroleum product may remain in place without a significant risk to human health. However, this most likely would not meet the nuisance odor criteria of TAGM 4046. Conversely, the SSTL for arsenic is less than the average site-specific background concentration and it is not appropriate to remediate inorganics below background concentrations.

For the purpose of evaluating corrective action objectives, the proposed action levels for organics in the soils should include a combination of the SSTLs and the TAGM 4046 criteria which outlines the use of the soil water partition model to calculate soil cleanup objectives. The SSTLs are derived from direct soil exposure scenarios for surface and subsurface soil and the values calculated by the soil water partition model are protective of groundwater quality. The lower of the two sets of values will be used as the corrective action level to be conservatively protective of human health and the environment.

A TOC value of eight-percent for backfill material and one-percent for the native soils was used in the partition model. The on-site groundwater SSTL was used for the water quality concentration (C_w) in the model. The calculated "On-Site Groundwater Quality Protection Values" for the fill material and native soils are presented in Table 3-2. With the exception of benzo(a)pyrene, groundwater quality protection values were not calculated for compounds for which SSTLs were not developed in the Exposure Assessment. SSTLs for groundwater were not developed for certain organic compounds because they were either not detected in the groundwater samples or there are no toxicological criteria for the scenarios evaluated. SSTLs were developed for organic indicator compounds (i.e., vinyl chloride at 2 µg/l) that would be protective for those associated compounds where no SSTL was developed (e.g., TCE). Therefore, it is reasonable to assume that the contaminant concentrations are below the actual groundwater quality protection values within the soil.

Benzo(a)pyrene was used as an indicator compound for PAH contamination in soil across the site, therefore a groundwater SSTL was calculated in this report so a groundwater quality protection value could be developed. The benzo(a)pyrene SSTL was calculated using the same assumptions and exposure pathways as for the other carcinogenic PAHs in the Exposure Assessment.

The soil saturation concentrations calculated in the Exposure Assessment were also considered during the evaluation of the on-site soil corrective action objectives to avoid leaving free product in the soil. A value 90% of the calculated soil saturation concentrations was compared to the SSTLs and groundwater quality protection values. The lowest value was chosen as the soil corrective action objective. In addition to the corrective action objectives for individual compounds, the nuisance odor criteria from TAGM 4046 will also be included as an action level. TAGM 4046 references the Draft TOGs on Petroleum Contaminated Soil Guidance which indicates that insoluble compounds at high concentrations can exhibit a distinct odor even though the substance will not leach from the soil. Therefore, any time a soil exhibits a discernable odor nuisance, it shall not be considered clean even if it has met the numeric criteria. The use of the nuisance odor criteria will be used for the delineation and cleanup of the areas in which high concentrations of relatively insoluble petroleum hydrocarbons are present but individual compounds are not identified in the analytical results.

The NYSDEC soil cleanup criteria used for inorganics at the Perfection Plating site is applicable to the Siberia Area with the exception of the value for chromium, which is based on chromium in the hexavalent state. As outlined above, the only hexavalent chromium contamination in soil at the Siberia Area is related to the Perfection Plating site. Furthermore, hexavalent chromium was not detected in groundwater collected from elsewhere at the Siberia Area during the RFI. Thus, the SSTLs for chromium in soil and groundwater for the Siberia Area should be used as the corrective action objectives since they are based on trivalent chromium. A summary of the proposed corrective action objectives for soil is presented in Table 3-2.

3.2 Groundwater Corrective Action Objectives

Contamination above applicable standards has been encountered in the groundwater samples collected from monitoring wells screened in the overburden, weathered bedrock, and competent bedrock at the Siberia Area. As a point of reference, the federal and New York State groundwater standards have been compared to the groundwater analytical results from the site. These standards include the USEPA Maximum Contaminant Levels (MCLs), the NYS Class GA Drinking Water Standards, and the NYS MCLs. These standards are conservative values, meant to be protective of human health assuming the groundwater will be used as a potable water source. Risk-based, site specific target levels (SSTLs) have been developed based on the potential human exposure scenarios that may exist currently and/or in the future at the Siberia Area. The environmental parameters, chemical-specific parameters, exposure parameters, and toxicological criteria used to derive the SSTLs are outlined in the Exposure Assessment. The specific analytes for which groundwater SSTLs were developed in the Exposure Assessment were chosen based on their frequency of detection and on elevated concentrations. Exposure scenarios were evaluated resulting in various SSTLs for a given compound. The lowest SSTL from among those derived is presented in Table 3-1. Also included in Table 3-1 are water solubility limits for the organic chemicals of concern in groundwater. The water solubility limits are included for comparison purposes since, for some organic chemicals of potential concern in groundwater, the derivation of the SSTLs results in values that are greater than this physicochemical limit. These SSTLs are replaced in Table 3-1 with the notation that they are greater than the solubility limit.

3.2.1 Proposed Corrective Action Objectives for Groundwater

The individual compounds and analytes for which exceedances above the applicable standards were detected in groundwater samples have been selected as contaminants of concern for further evaluation in the Corrective Measures Study. Proposed cleanup objectives have been developed for these contaminants of concern for the evaluation of potential corrective measures. As summarized in Section 2.1.2, the exceedances in the groundwater from the Siberia Area monitoring wells include chlorinated VOCs, PAHs and total petroleum hydrocarbons.

Analytical results for unfiltered groundwater samples indicated concentrations of arsenic, chromium, and lead above applicable standards. However, filtered samples exceeded the standards at a much lower frequency, indicating that the elevated metals concentrations were primarily associated with the particulates. Due to the presence of arsenic, chromium, and lead at elevated concentrations in the soils, they will be considered as analytes of concern, however, corrective action objectives should be based on the dissolved concentrations.

The corrective action objectives should reflect the different exposure scenarios associated with on-site versus off-site groundwater contamination. As indicated in the Exposure Assessment, the groundwater resource in the area is not used as a potable water supply. Assuming that the groundwater has a potential to be used as a potable source off-site, the federal or state drinking water standards apply at the site boundaries to be protective of potential downgradient users/receptors. However, the SSTLs developed in the Exposure Assessment apply to the groundwater within the boundaries of the site. The proposed corrective action levels are presented in Table 3-3. In addition to the numerical corrective action objectives, a visual and/or olfactory criteria (i.e., petroleum sheen and/or odor) will also be used for petroleum hydrocarbon contamination observed during the field activities and in the groundwater screening results. The use of the visual petroleum sheen and petroleum odor criteria will be used for the delineation and cleanup of the areas in which concentrations of petroleum hydrocarbons are present but individual compounds are not identified in the analytical results.

3.3 Off-Site Surface Soil and Sediment Corrective Action Objectives

Off-site surface soil and sediment SSTLs have been developed in the Exposure Assessment factoring in resident adults and children as potential receptors. The contaminants of concern at the site perimeters are PAHs and arsenic, chromium, and lead. The same corrective action objectives will be used for the off-site surface soil and sediment as for the on-site surface soil (except the off-site SSTLs replace the on-site SSTLs). The lower value between the off-site surface soil and sediment SSTLs and the TAGM 4046 criteria which outlines the use of the soil water partition model to calculate soil cleanup objectives should be used as the action level to be conservatively protective of human health and the environment.

4.0 AREAS OF CONCERN

The areas of concern (AOCs) for each impacted media have been identified based on the analytical data, field observations, historical site information, and site specific corrective action levels. Quantities of the impacted medium have been estimated for the purposes of performing the screening of the corrective measures technologies.

4.1 On-Site Soil AOCs

The AOCs with respect to the soil media have been determined based on the nature and extent of contamination summarized in Section 2.1.1 and the site specific corrective action levels outlined in Section 3.1. For the purpose of evaluating appropriate treatment technologies and combinations of technologies, the AOCs have been identified in terms of contaminant type(s), depths, media, and areal distribution across the Siberia Area.

The analytical data were imported into the computer modeling program "Groundwater Modeling System" (GMS) developed by Brigham Young University for the United States Department of Defense. The GMS software was used to generate three-dimensional contour models to aid in the evaluation of the distribution of the contamination. The values identified as the proposed corrective action objectives (i.e., action levels) were used for the lowest contour interval within GMS in order to identify the extent of the soil that may require remediation. This exercise was performed for PAHs, arsenic, chromium, and lead. Since the soils impacted by VOCs are limited to the immediate area surrounding 95MPI-MW32 in the NE Quadrant, the extent of these impacted soils was manually estimated without using GMS.

The carcinogenic PAH benzo(a)pyrene was chosen as an indicator parameter to estimate the extent of PAH contamination potentially requiring remediation within the surface and subsurface soil in the Siberia Area. Benzo(a)pyrene was used because of its relatively low corrective action levels and its high frequency of detection throughout the site. Each sample which had an exceedance of any individual carcinogenic PAH SSTL also contained benzo(a)pyrene above its corresponding SSTL.

Relatively low concentrations of benzo(a)pyrene were quantified (i.e., 10 to 100 µg/kg) in more than twenty percent of the soil samples, however the reported quantitation limit for benzo(a)pyrene was generally at or above 330 µg/kg. The samples which did not contain detectable concentrations of benzo(a)pyrene were reported by the laboratory as less than the quantitation limit, which was greater than the surface soil SSTL of 315 µg/kg. Therefore, the carcinogenic PAH concentrations reported below the method detection limit were imported into GMS as zero values to avoid interpolation using false positive results across the site. In addition, since Building 145 was constructed the year after the Siberia Area was purchased by the Arsenal, it is reasonable to assume that the soil beneath the building has not been contaminated in a similar manner as the rest of the site. Since contamination under Building 145 is unlikely, zero concentration values were inserted at the building perimeter to force GMS to contour around it.

The extent of PAH contamination in the on-site surface soils was estimated by contouring the benzo(a)pyrene concentrations using 315 µg/kg (i.e., the on-site surface soil corrective action level) as the lowest contour interval. The entire sample population from the RFI and additional CMS field activities was contoured. These data include surface and subsurface soil samples from zero to six feet below the ground surface. Because a different cleanup objective is appropriate for the surface soil (i.e., zero to one foot below the ground surface), it was separated from the GMS grid (Figure 4-1) for volume estimation and areal extent evaluation. The entire benzo(a)pyrene data set was then re-contoured using 4627 µg/kg (i.e., the corresponding subsurface soil corrective action level) as the lowest contour interval. The subsurface soil (i.e., one to six feet below the ground surface) was then separated from the GMS grid (Figure 4-2) and evaluated with respect to the impacted volume and areal extent estimation. In Figures 4-3 through 4-5, the PAH and TPH subsurface soil contamination has also been shown in plan view in three separate layers (one to two feet, two to four feet, and four to six feet bgs) with the benzo(a)pyrene concentrations posted on the appropriate layer. The extent of contaminated soil exhibiting nuisance odors and staining was also estimated and superimposed on Figure 4-3 through 4-5 to evaluate the extent of PAH and TPH contamination in soil.

The extent of inorganic contamination was determined in a similar manner by contouring the individual arsenic (Figures 4-6 through 4-10), and lead (Figure 4-11 through 4-15) concentrations using the associated corrective action levels for the lowest contour interval. The chromium concentrations did not exceed the on-site corrective action objectives and were therefore not contoured.

4.1.1 Northeast Quadrant Soil AOCs

4.1.1.1 Northeast Quadrant Surface Soil

The results of the data interpolation indicate that benzo(a)pyrene concentrations (used as an indicator of carcinogenic PAHs) above the on-site surface soil corrective action level of 315 µg/kg are ubiquitous across the Siberia Area within the upper foot of the overburden. The surface soil within the Northeast Quadrant which exceeds the PAH Corrective Action Level has been broken out as an individual AOC designated as NE-Soil-01.

Clean surface soils along the eastern fence line have been recently placed in the area remediated during the NYSDEC removal action associated with contamination from the Perfection Plating site. This area has been eliminated from the NE-Soil-01 areal extent estimation. However, surface soils that contain inorganic compounds in addition to PAHs above the action levels in the Northeast Quadrant still remain near the northern and eastern fence lines. These surface soils have been designated as a separate AOC due to the presence of multiple contaminant types. The presence of inorganics in addition to PAHs warrants the evaluation of additional and/or separate remedial alternatives than may be applicable for soils impacted only by PAHs. This AOC has been designated NE-Soil-02, as shown on Figure 4-16. The estimated volumes of the inorganic/PAH-contaminated soil and the estimated remaining surface soil in the Northeast Quadrant that are contaminated above the proposed on-site action levels are presented in Table 4-1. The area displaced by the newly installed reactive wall pilot treatment system has also been removed from the area calculation for NE-Soil-02.

4.1.1.2 Northeast Quadrant Subsurface Soil

An area of contaminated subsurface soil which exceeds the Corrective Action Objectives for PAHs as well as the nuisance odor criteria has been identified in the vicinity of 95MPI-MW-32, between the southern reactive wall segment and MW-EA-6. This AOC has been designated as NE-Soil-03, as shown on Figure 4-17. Based on the available analytical data and field observations made during the subsurface investigation activities, an area approximately 75 feet wide by 150 feet long has been identified in the vicinity. The total depth of the contamination appears to extend to approximately six to seven feet bgs. At this depth, a continuous clay layer exhibiting high plasticity overlies the weathered bedrock. The depth to the water table surface has historically ranged from approximately 2.5 to 3.5 feet bgs in 95MPI-MW-32, which is screened in the surficial fill and clayey silt units. The estimated volume of the subsurface overburden material exhibiting TPH and PAH contamination above the cleanup objectives is presented in Table 4-1. A total depth of the soil AOC of four feet below the ground surface has been estimated. The remaining vertical extent of contamination, which is below the water table, is considered a groundwater AOC. Based on the limited seepage observed during previous trenching activities at the site, however, it may be feasible to treat the contamination in the low permeability saturated soils concurrently using the same methods as the vadose zone soils. From a practical stand point, this approach may be particularly effective for the areas in which the extent of contamination is limited to depths less than six to eight feet below the ground surface.

The inorganic contamination in the Northeast Quadrant is generally concentrated near the northern and eastern fence lines and limited to the upper two feet of soil. The subsurface soil portion (i.e., > one foot bgs) of this contaminated area has been designated as NE-Soil-04. The volume of subsurface soil in NE-Soil-04 exceeding the inorganic cleanup objectives is presented in Table 4-1. Several isolated areas in the central area of the Northeast Quadrant also contained inorganic concentrations above the cleanup objectives, however the average concentrations within these soils were well below these action levels.

4.1.2 Northwest Quadrant Soil AOCs

4.1.2.1 Northwest Quadrant Surface Soil

The results of contouring the benzo(a)pyrene concentrations indicate that PAHs above the Cleanup Objectives are ubiquitous across the Northwest Quadrant within the upper foot of the overburden, however, approximately one half of the Northwest Quadrant is covered with concrete and/or asphalt. Since this cover limits the exposure pathways to the underlying surface soil, the scenarios used to derive the subsurface soil SSTLs in the Exposure Assessment are more applicable. Therefore, the subsurface soil Cleanup Objectives (i.e., the subsurface soil SSTLs) will be used for the concrete and asphalt covered areas.

Based on the GMS modeling, the remaining uncovered surface soils include an area along the northern and eastern fence line containing arsenic as well as PAHs above the Cleanup Objectives. This inorganic and PAH contaminated AOC is designated NW-Soil-01 on Figure 4-16. The remaining surface soil in the Northwest Quadrant that is contaminated with PAHs above the proposed on-site action level is designated as NW-Soil-02. The estimated volume of these two AOCs is presented in Table 4-1.

4.1.2.2 Northwest Quadrant Subsurface Soil

An area of contaminated subsurface soil which exceeds the Corrective Action Objectives for PAHs as well as the nuisance odor criteria has been identified near the northwest corner of the Siberia Area. This AOC is designated as NW-Soil-03 as shown in Figure 4-17. Petroleum odors, staining, and occasional product globules have been observed in the overburden material in excess of 20 feet bgs in this area. The depth to the water table historically has ranged from approximately 2 to 3.5 feet bgs in monitoring wells 95MPI-MW-20, 95MPI-MW-21, and 95MPI-MW-37; which are all screened in the shallow overburden. The estimated volume of the NW-Soil-03 AOC, assuming an average contamination depth of four feet bgs, is presented in Table 4-1. The remaining vertical extent of contamination, which is below the water table, is considered a groundwater AOC.

The inorganic contamination in the NW Quadrant is generally concentrated at the northern and western fence lines and limited to the upper two feet of soil. The subsurface soil portion (i.e., > one foot bgs) of this contaminated area has been designated as NW-Soil-04. The estimated volume of subsurface soil in NW-Soil-04 exceeding the inorganic cleanup objectives is presented in Table 4-1.

4.1.3 Southeast Quadrant Soil AOCs

4.1.3.1 Southeast Quadrant Surface Soil

The results of data interpolation of the benzo(a)pyrene concentrations indicate that PAHs above the Cleanup Objectives are ubiquitous across the Southeast Quadrant within the upper foot of the overburden. This PAH-contaminated AOC is designated SE-Soil-01 on Figure 4-16. The estimated volume of this AOC is presented in Table 4-1.

4.1.3.2 Southeast Quadrant Subsurface Soil

An area of contaminated subsurface soil that exceeds the Corrective Action Objectives for PAHs as well as the nuisance odor criteria has been identified in the vicinity of the Lumberyard and Storage Area. This AOC is designated as SE-Soil-02 as shown in Figure 4-17. Petroleum odors and staining have been observed in the overburden as deep as eight feet bgs in this area. The depth to the water table historically has ranged from approximately 1.5 to 3.5 feet bgs in monitoring wells 95MPI-MW-26, and 95MPI-MW-35; which are screened in the shallow overburden. The estimated volume of the SE-Soil-03 AOC is presented in Table 4-1. A total depth of the soil AOC of four feet below the ground surface has been estimated. The remaining vertical extent of contamination, which is below the water table, is considered a groundwater AOC. Based on the limited seepage observed during previous trenching activities at the site, however, it may be feasible to treat the contamination in the low permeability saturated soils concurrently using the same methods as the vadose zone soils. From a practicality stand point, this approach may be particularly effective for the areas in which the extent of contamination is limited to depths less than six to eight feet below the ground surface.

4.1.4 Southwest Quadrant Soil AOCs

4.1.4.1 Southwest Quadrant Surface Soil

The Main Electrical Substation is located in the Southwest Quadrant. The actual substation contains electrical transformers and appurtenances and has a chain link fence around the perimeter. Gravel covers most of the Main Substation surface area and extends approximately two feet outside of its perimeter fence. Nearly all of the remainder of the Southwest Quadrant is covered with concrete and/or asphalt. Since this cover limits the exposure pathways to the underlying surface soil, the scenarios used to derive the subsurface soil SSTLs in the Exposure Assessment are more applicable. Therefore, the subsurface soil Cleanup Objectives (i.e., the subsurface soil SSTLs) will be used for the gravel, concrete, and asphalt covered areas of the Southwest Quadrant.

4.1.4.2 Southwest Quadrant Subsurface Soil

An area of contaminated subsurface soil that exceeds the Corrective Action Objectives for PAHs as well as the nuisance odor criteria has been identified throughout the Main Substation Area, from the southern fence line of the Siberia Area to Building 145. Inorganic analyte concentrations above the corrective action levels have been estimated to extend over approximately one quarter of the area. This area containing inorganic and organic contamination has been designated as SW-Soil-01, as shown in Figure 4-17. The total depth of the metals contamination is estimated as four feet below the ground surface.

The data indicate that the remaining portion of the Main Substation Area contains PAHs and TPH contamination above the Corrective Action Levels. This area has been broken out as a separate AOC designated as SW-Soil-02 as shown in Figure 4-17. Elevated PAH and TPH concentrations as well as petroleum odors and staining have been observed in the overburden as deep as eight feet bgs throughout the Main Substation Area. The depth to the water table historically has ranged from approximately 2.5 to 3.5 feet bgs in monitoring well 95MPI-MW-27 just east of the Main Substation, and 5.5 to 6.8 in 95MPI-MW-29 west of the Main Substation. 95MPI-MW-27 and 95MPI-MW-29 are both screened in the shallow overburden. The estimated volumes of the SW-Soil-01 and SW-Soil-02 AOCs are presented in Table 4-1, assuming an average depth of four feet bgs. The remaining vertical extent of contamination is considered a groundwater AOC. Based on the limited seepage observed during previous trenching activities at the site, however, it may be feasible to treat the contamination in the low permeability saturated soils concurrently using the same methods as the vadose zone soils.

4.2 On-Site Groundwater AOCs

The AOCs with respect to the groundwater contamination have been determined based on the nature and extent of contamination summarized in Section 2.1.2 and the site-specific corrective action levels outlined in Section 3.2. For the purposes of evaluating the treatment technologies, the AOCs have been identified in terms of contaminant type and hydrogeologic units impacted.

Elevated total petroleum hydrocarbons have been detected in groundwater samples from areas of the site containing odorous and stained soil as well as elevated PAHs. A sheen and petroleum odor were also noted during monitoring well development and groundwater sampling activities within these areas. However, the results from the Target Compound List (TCL) analyses indicated relatively few contaminant concentrations above groundwater standards in these areas. In the absence of elevated concentrations of TCL parameters, the combination of TPH and visual observations will be used to determine groundwater AOCs.

These groundwater AOCs are generally beneath the areas identified in Section 4.1 as soil AOCs exceeding the nuisance odor criteria.

4.2.1 Northeast Quadrant Groundwater AOCs

A VOC contaminant plume was identified in the saturated overburden and weathered bedrock in the Northeast Quadrant. This AOC has been designated as NE-GW-01. A permeable reactive barrier wall pilot treatment system using zero valent iron as the reactive medium has been installed. This pilot treatment system intersects the entire width of the chlorinated organic plume in two locations within the Northeast Quadrant to preclude contamination migration to the sewer and off-site. The permeable reactive wall is an innovative, in-situ treatment system and its effectiveness will be evaluated by monitoring groundwater for VOCs before and after the reactive medium as well as at the perimeter of the site. If the pilot treatment system successfully reduces the off-site migration of VOCs, it will be proposed that it remain as a stand-alone, permanent remedial solution for the overburden and weathered bedrock VOC plume in the Northeast Quadrant.

Chlorinated VOCs exceeding groundwater action levels have also been detected from bedrock monitoring wells (specifically 98MPI-MW-41) within the Northeast Quadrant. However, the available data indicate that the contamination appears to be limited to the immediate vicinity of the suspected source area and does not extend to the downgradient monitoring wells and/or off-site. This bedrock contaminated AOC has been designated as NE-GW-02.

The GC/FID field screening results from a groundwater sample collected approximately 50 feet southwest of 95MPI-MW-32 indicated petroleum hydrocarbon contamination. This corresponds to the petroleum-contaminated soil AOC observed in the vicinity of 95MPI-MW-32 (designated as NE-Soil-03). The groundwater AOC is designated as NE-GW-03 and the same lateral extent of contamination is assumed (Figure 4-17). The vertical extent of the groundwater AOC is estimated to be seven feet bgs based on the observed staining and odors in the saturated soil.

The PAH concentrations did not exceed the on-site corrective action objectives, however, PAHs above the site boundary corrective action levels were detected in several second round RFI groundwater samples from monitoring wells across the Northeast Quadrant. Since the exceedances were limited to the second round samples, further evaluation of the data trends will be made as part of the groundwater monitoring program for the entire Arsenal to determine the potential for off-site migration of contamination above the site boundaries corrective action objectives.

4.2.2 Northwest Quadrant Groundwater AOCs

The GC/FID field screening results from approximately 60 feet east of 95MPI-MW-20 indicated petroleum hydrocarbon contamination. A petroleum odor from the groundwater extracted from 95MPI-MW-36 and 95MPI-MW-37 was also noted during development of the wells. Both of these areas are within the petroleum-contaminated soil AOC observed in the northwest corner of the site (designated as NW-Soil-03). This groundwater AOC is designated as NE-GW-01 and the same lateral extent of contamination as NW-Soil-03 is assumed (Figure 4-17). The vertical extent of contamination is estimated at 20 feet bgs based on the depth of staining and petroleum odors observed. PAHs above the on-site and site boundaries corrective action levels were not detected in groundwater samples from the Northwest Quadrant.

4.2.3 Southeast Quadrant Groundwater AOCs

The GC/FID field screening results from a groundwater sample collected approximately 20 feet west of 95MPI-MW-35 indicated petroleum hydrocarbon contamination in the overburden. Previous investigations also identified petroleum hydrocarbons in groundwater samples from monitoring wells ESE-2 and GTI-3, which are screened in the shallow bedrock. A sheen was noted during development of 95MPI-MW-35.

PAHs were not detected above the on-site or off-site corrective action objectives in the round one samples, however, benzo(a)pyrene and chrysene were detected above the off-site corrective action levels in the second round groundwater sample from 95MPI-MW-35. With the exception of GTI-3, these monitoring wells are within the petroleum-contaminated soil AOC observed in the Southeast Quadrant designated as SE-Soil-03. This groundwater AOC is designated as SE-GW-01 and the same lateral extent of contamination as SE-Soil-03 is assumed (Figure 4-17) based on the extent of contamination observed in the saturated soils. The vertical extent of contamination is estimated to be approximately 6 feet bgs based on the depth of staining and petroleum odors observed.

4.2.4 Southwest Quadrant Groundwater AOCs

The GC/FID field screening results from two groundwater samples collected in the Southwest Quadrant indicated petroleum hydrocarbon contamination in the overburden. Petroleum hydrocarbons have also been detected in groundwater samples from monitoring well ESE-5, which is screened in the shallow bedrock. A sheen was also noted during development of 95MPI-MW-31. PAHs were not detected above the on-site or site boundary corrective action objectives in the round one or round two samples. This groundwater AOC is designated as SW-GW-01 and the same lateral extent of contamination as SW-Soil-01 and SW-Soil-02 is assumed (Figure 4-17) based on the extent of contamination observed in the saturated soils. The vertical extent of contamination is estimated to extend to approximately 8 feet bgs based on the depth of staining and petroleum odors observed.

4.3 Off-Site Surface Soil and Sediment AOCs

Concentrations of PAHs as well as arsenic and lead were detected above the off-site surface soil corrective action objectives along the northern fence line of the Siberia Area. This AOC has been designated Offsite-Soil-01 and extends approximately 640 feet east from the northwest corner of the facility fence, between the northern fence line and 12th Street. An area east of the Delaware and Hudson Railroad tracks is also included in this AOC. The Areal extent is shown on Figure 4-16. The vertical extent of the AOC is zero to one foot below the ground surface.

5.0 PRELIMINARY SCREENING OF CM TECHNOLOGIES

Various remedial technologies were evaluated to determine the potential of achieving site remedial objectives using both conventional and innovative remedial alternatives. The evaluation was performed by compiling information from various sources including the USEPA VISITT data base, the Department of Defense Remediation Technologies Screening Matrix, and Malcolm Pirnie personnel. The technology-specific information is presented in the following subsections. The applications of potential remedial alternatives were screened according to geologic and hydrogeologic conditions, chemical contamination in affected media, engineering requirements, and cost. The costs presented herein include broad ranges to cover a variety of potential scenarios. Remedial designs, even at the conceptual level, have not yet been performed. The presented costs are for comparative purposes only. Capital costs as well as operation and maintenance (O&M) are included within the ranges, where appropriate. Engineering, administrative, legal, and permitting costs are not included in the ranges. A summary of the screened technologies for soil and groundwater is presented in Table 5-1 and Table 5-2, respectively.

5.1 Preliminary Screening For Soil Media

INSITU TECHNOLOGIES

Natural Attenuation

Description

For natural attenuation in soils, natural biotransformation processes such as dilution, dispersion, volatilization, biodegradation, adsorption, and chemical reactions with soil materials can reduce contaminant concentrations to acceptable levels. Natural attenuation may be considered for remediation of contaminants in 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,
- For the persistent or conserved contaminants, ensured containment during and after natural attenuation.

Applicability

Target contaminants for natural attenuation are VOCs and 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.

Limitations

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.
- Contaminants may migrate (erosion, leaching, and volatilization) before they are degraded or transformed.

Costs

There are costs for modeling contamination degradation rates to determine whether natural attenuation is a feasible remedial alternative. Additional costs are for appropriate containment, surface and subsurface sampling and sample analysis (potentially extensive) to determine the extent of contamination and confirm contaminant degradation rates and cleanup status. Skilled labor hours are required to conduct the modeling, sampling, and analysis. O&M costs would be required for monitoring to confirm that contaminant migration has not occurred.

Site Relevance

A conceptual site model and long-term monitoring program is already in place for the Siberia Area. Additionally, bench-scale treatability studies have indicated that TPH's and PAH's are being readily degraded aerobically onsite. Therefore, additional costs for evaluating natural attenuation would be relatively low for any of the areas of concern. This technology is relevant for the Siberia Area and will be considered further.

<u>Enhanced Bioremediation</u>

Description

Enhanced bioremediation is a process in which indigenous or inoculated microorganisms (e.g., fungi, bacteria, and other microbes) degrade (metabolize) organic contaminants found in soil and/or ground water, converting them to innocuous end products. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials. Aerobic micro-organisms, in the presence of sufficient oxygen (aerobic conditions), and other nutrient elements, will ultimately convert many organic contaminants to carbon dioxide, water, and microbial cell mass. Anaerobic microorganisms, in the absence of oxygen (anaerobic conditions), will ultimately metabolize the organic contaminants to methane, limited amounts of carbon dioxide, and trace amounts of hydrogen gas. Under sulfate-reduction conditions, sulfate is converted to sulfide or elemental sulfur, and under nitrate-reduction conditions, dinitrogen gas is ultimately produced. 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 vinyl chloride. To avoid such problems, most bioremediation projects are conducted in situ. Vinyl chloride can easily be broken down further if aerobic conditions are created.

Applicability

Bioremediation techniques have been successfully used to remediate soils, sludges, and ground water contaminated with petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Bench- and pilot-scale studies have demonstrated the effectiveness of anaerobic microbial degradation of nitrotoluenes in soils contaminated with munitions wastes. 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. These techniques, while still largely experimental, show considerable promise of stabilizing or removing inorganics from soil.

Limitations

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

- Low permeability soils onsite may prohibit contaminant-microorganism contact and decrease the potential to achieve site cleanup goals.
- The circulation of water-based solutions through the soil may increase contaminant mobility and necessitate treatment of underlying ground water.
- Preferential colonization by microbes may occur causing clogging of nutrient and water injection wells.
- 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 when the system is used for clay, highly layered, or heterogeneous subsurface environments because of oxygen (or other electron acceptor) transfer limitations.
- High concentrations of heavy metals, highly chlorinated organics, long chain hydrocarbons, or inorganic salts are likely to be toxic to microorganisms.
- Bioremediation slows at low temperatures.

Many of the above factors can be controlled with proper attention to good engineering practice.

Costs

Typical costs for enhanced bioremediation range from $20 to $80 per cubic yard of soil. Variables affecting the cost are the nature and depth of the contaminants, and use of bio-augmentation.

Site Relevance

Bio-treatability studies conducted to date indicate that aerobic bio-degraders exist onsite and they are using the TPH and PAHs as a source of carbon. Removal of the recalcitrant PAHs to concentrations below regulatory standards may be a problem because the low permeability subsoils and degree of heterogeneity may prohibit contaminant-microorganism contact (bioavailability). Therefore, bio-enhancement (i.e. introduction of heat, nutrients, oxygen, physical mixing, etc.) may be necessary to increase bioavailability and the potential for bioremediation of the PAHs to meet the corrective action objectives. This technology is relevant for remediation at the Siberia Area and will be considered further.

Chemical Reduction/Oxidation

Description

Reduction/oxidation (Redox) reactions chemically convert hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. Redox reactions involve the transfer of electrons from one compound to another. Specifically, one reactant is oxidized (loses electrons) and one is reduced (gains electrons). The oxidizing agents most commonly used for treatment of hazardous contaminants are ozone, hydrogen peroxide, hypochlorites, and chlorine dioxide. Chemical redox is a full-scale, well-established technology used for disinfection of drinking water and wastewater, and it is a common treatment for cyanide wastes. Enhanced systems are now being used more frequently to treat contaminants in soils.

Applicability

The target contaminant group for chemical redox is organics. The technology is very effective for halogenated VOCs. It can be used but may be less effective against nonhalogenated VOCs and SVOCs, petroleum hydrocarbons and pesticides.

Limitations

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

- Incomplete oxidation or formation of intermediate contaminants may occur depending upon the contaminants and oxidizing agents used.
- The process is not cost-effective for high contaminant concentrations because of the large amounts of oxidizing agent required.
- Oil and grease in the media should be minimized to optimize process efficiency.

Costs

Available estimated costs range from $150 to $500 per cubic yard.

Site Relevance

The primary contaminants in the Siberia Area soils are petroleum hydrocarbons, and to a lesser extent, halogenated hydrocarbons and metals. The Redox process can be volatile within the subsurface and costly, however it has the ability to remove the hydrocarbon contaminants over a very short period of time. A primary limiting factor may be the oil saturated soils. These soils may not be remediated efficiently due to their saturated nature with petroleum contaminants. The heterogeneity of the soils in the Siberia Area would also present logistical problems with respect to reagent distribution, further increasing costs. Therefor this technique will not be considered further for the soil matrix.

Soil Flushing

Description

In situ soil flushing is the extraction of contaminants from the soil with water or other suitable aqueous solutions. Soil flushing is accomplished by passing the extraction fluid through in-place soils using an injection or infiltration process. Extraction fluids must be recovered from the underlying aquifer and, when possible, they are recycled.

Cosolvent Enhancement

Cosolvent flushing involves injecting a solvent mixture (e.g., water plus a miscible organic solvent such as alcohol) into either vadose zone, saturated zone, or both to extract organic contaminants. Cosolvent flushing can be applied to soils to dissolve either the source of contamination or the contaminant plume emanating from it. The cosolvent mixture is normally injected upgradient of the contaminated area, and the solvent with dissolved contaminants is extracted downgradient and treated above ground.

Recovered ground water and flushing fluids with the desorbed contaminants may need treatment to meet appropriate discharge standards prior to recycle or release to local, publicly owned wastewater treatment works or receiving streams. To the maximum extent practical, recovered fluids should be reused in the flushing process. The separation of surfactants from recovered flushing fluid, for reuse in the process, is a major factor in the cost of soil flushing. Treatment of the recovered fluids results in process sludges and residual solids, such as spent carbon and spent ion exchange resin, which must be appropriately treated before disposal. Air emissions of volatile contaminants from recovered flushing fluids should be collected and treated, as appropriate, to meet applicable regulatory standards. Residual flushing additives in the soil may be a concern and should be evaluated on a site-specific basis. The duration of soil flushing process is generally short- to medium-term.

Applicability

The target contaminant group for soil flushing is primarily inorganics. The technology can also be used to treat VOCs, SVOCs, fuels, and pesticides, but it may be less cost-effective than alternative technologies for these contaminant groups. The addition of environmentally compatible surfactants may be used to increase the effective solubility of some organic compounds; however, the flushing solution may alter the physical/chemical properties of the soil system. The technology offers the potential for recovery of metals and can mobilize a wide range of organic and inorganic contaminants from coarse-grained soils.

Limitations

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

- Low permeability or heterogeneous soils are difficult to treat.

- Surfactants can adhere to soil and reduce effective soil porosity.
- Reactions of flushing fluids with soil can reduce contaminant mobility.
- The potential of washing the contaminant beyond the capture zone and the introduction of surfactants to the subsurface concern regulators. The technology should be used only where flushed contaminants and soil flushing fluid can be contained and recaptured.
- Aboveground separation and treatment costs for recovered fluids can drive the economics of the process.

Costs

The cost of soil flushing depends greatly on the type and concentration of surfactants used, if they are used at all. Rough estimates ranging from $25 to $250 per cubic yard have been reported.

Site Relevance

Obtaining hydraulic control and introducing surfactants to treat low permeability soils is problematic at the Siberia Area. Also, capturing the flushing fluids and contaminants is difficult to do in a low permeability soil without installing a number of wells or increasing soil permeability by another method (i.e., radio frequency heating or pneumatic fracturing). Additionally, an ex-situ treatment system would be required to treat the effluent. The addition of engineering controls for increasing the soil permeability and capturing/treating the effluent would most-likely drive the unit cost for soil flushing towards the high end of the range referenced above. Therefor, the overall costs associated with type of remedial measure would not be a cost-effective approach for this site and this technique will not be considered further.

Solidification/Stabilization/Chemical Fixation

Description

Solidification/stabilization (S/S) reduces the mobility of hazardous substances and contaminants in the environment through both physical and chemical means. Unlike other remedial technologies, S/S seeks to trap or immobilize contaminants within their "host" medium (i.e., the soil, sand, and/or building materials that contain them), instead of removing them through chemical or physical treatment. Leachability testing is typically performed to measure the immobilization of contaminants. S/S techniques can be used alone or combined with other treatment and disposal methods to yield a product or material suitable to be left on-site, for land disposal or, to be applied to beneficial use. These techniques have been used as both final and interim remedial measures.

Auger/caisson systems and injector head systems are techniques used in soil S/S. These systems apply S/S agents to soils to trap or immobilize contaminants.

Bottom barriers are horizontal subsurface barriers that prevent vertical migration by providing a floor of impermeable material beneath the waste. The installation of a grout injection bottom barrier involves directional drilling with forced grout injection. Implementation of this technology is highly dependent on the physical properties of soil.

Applicability

The target contaminant group for in situ S/S is generally inorganics. The Auger/Caisson and Reagent/Injector Head Systems have limited effectiveness against SVOCs and pesticides and no expected effectiveness against VOCs; however, systems designed to be more effective in treating organics are being developed and tested.

Limitations

Factors that may limit the applicability and effectiveness of the in situ S/S include:

- Depth of contaminants may limit some types of application processes.
- Future usage of the site may "weather" the materials and affect ability to maintain immobilization of contaminants.
- Some processes result in a significant increase in volume (up to double the original volume).
- Certain wastes are incompatible with variations of this process. Treatability studies are generally required.
- Reagent delivery and effective mixing are more difficult than for ex situ applications.

- Like all in situ treatments, confirmatory sampling can be more difficult than for ex situ treatments.
- Processing of contamination below the water table may require dewatering.

Cost

Costs for Auger/Caisson and Reagent/Injector Head Systems processes vary widely according to materials or reagents used, their availability, project size, and chemical nature of contaminants (e.g., types and concentration levels for shallow applications). The in situ soil mixing/auger techniques average $30 to $60 per cubic yard for the shallow applications and $150 to $250 per cubic yard for the deeper applications. The shallow soil mixing technique processes 40 to 80 tons per hour on average and the deep soil mixing technique averages 20 to 50 tons per hour. The major factor driving the selection process beyond basic waste compatibility is the availability of suitable reagents. Auger/Caisson and Reagent/Injector Head Systems processes require potentially large volumes of bulk reagents and additives to be transported to project sites. Transportation costs can dominate project economics and can quickly become uneconomical in cases where local or regional material sources are unavailable. The cost for grout injection varies depending on site-specific conditions. Costs for drilling can range from $50 to $150/ft and grouting from $50 to $75/ft, not including mobilization, wash disposal, or adverse site condition expenses.

Site Relevance

The variability in the delivery of agents can be significant in the low permeability overburden. Using agents of this nature will decrease the subsoil permeability and therefore, will reduce the effectiveness of other technologies that may be used concurrently. However, this technique may be applicable in areas where inorganics are inaccessible, such as the Main Substation or in subsurface "hot spots". Therefor, this technique is relevant for remediation of inorganics at the site and will be considered further.

Vitrification

Description

Solidification reduces the mobility of hazardous substances and contaminants in the environment by trapping or immobilizing contaminants within their "host" medium (i.e., the soil, sand, and/or building materials that contain them), instead of removing them through chemical or physical treatment. Leachability testing is typically performed to measure the immobilization of contaminants. Solidification can be used alone or combined with other treatment and disposal methods to yield a product or material suitable for disposal or, in other cases, that can be applied to beneficial use.

In-situ vitrification (ISV) is an in situ solidification process that uses an electric current to melt soil or other earthen materials at extremely high temperatures (1,600 to 2,000 °C or 2,900 to 3,650 °F) and thereby immobilize most inorganics and destroy organic pollutants by pyrolysis. Inorganic pollutants are incorporated within the vitrified glass and crystalline mass. Water vapor and organic pyrolysis combustion products are captured in a hood, which draws the contaminants into an off-gas treatment system that removes particulates and other pollutants from the gas. The vitrification product is a chemically stable, leach-resistant, glass and crystalline material similar to obsidian or basalt rock. The process destroys and/or removes organic materials. Heavy metals are retained within the molten soil. The time frame for the in situ ISV process is typically short-term.

Applicability

Although the target contaminant group for in situ solidification is typically inorganics, the process has been tested on a broad range of VOCs and SVOCs, other organics including dioxins and PCBs. The ISV process can destroy or remove organics and immobilize most inorganics in contaminated soils, sludge, or other earthen materials.

Limitations

Factors that may limit the applicability and effectiveness of the in situ solidification include:

- Depth of contaminants may limit the application process.
- Future usage of the site may "weather" the materials and affect ability to maintain immobilization of contaminants.
- Some processes result in a significant increase in volume (up to double the original volume).
- Like all in situ treatments, confirmatory sampling can be more difficult than for ex-situ treatments.
- The solidified material may hinder future site use.

Costs

For ISV, average costs for treatability tests (all types) are $25K plus analytical fees. Equipment mobilization and demobilization costs are $200K to $300K combined. Vitrification operation cost varies with electricity costs, quantity of water, and depth of process. Available unit costs range from $60 to $750 per cubic yard for full-scale remediation.

Site Relevance

Extremely high temperatures are required for the in-situ vitrification approach. This approach uses electricity to create a crystalline mass. This not only presents a safety problem for the active site, but also inhibits the ability to get to deeper contaminated zones. Existing structures in some areas would preclude the use of this technology. In addition, the shallow depth to the water table and relatively limited unsaturated zone further reduces the effectiveness of ISV. This technique is not relevant for site remediation and will not be considered further.

Electrokinetic Separation

Description

The principle of electrokinetic remediation (ER) relies upon application of a low-intensity direct current through the soil between ceramic electrodes that are divided into a cathode array and an anode array. This mobilizes charged species, causing ions and water to move toward the electrodes. Metal ions, ammonium ions, and positively charged organic compounds move toward the cathode. Anions such as chloride, cyanide, fluoride, nitrate, and negatively charged organic compounds move toward the anode. The current creates an acid front at the anode and a base front at the cathode. This generation of acidic condition in situ may help to mobilize sorbed metal contaminants for transport to the collection system at the cathode.

The two primary mechanisms transport contaminants through the soil towards one or the other electrodes: electro-migration and electro-osmosis. In electro-migration, charged particles are transported through the substrate. In contrast, electro-osmosis is the movement of a liquid containing ions relative to a stationary charged surface. Of the two, electro-migration is the main mechanism for the ER process. The direction and rate of movement of an ionic species will depend on its charge, both in magnitude and polarity, as well as the magnitude of the electro-osmosis induced flow velocity. Non-ionic species, both inorganic and organic, will also be transported along with the electro-osmosis induced water flow.

Two approaches are taken during electrokinetic remediation: "Enhanced Removal" and "Treatment without Removal". "Enhanced Removal" is achieved by electrokinetic transport of contaminants toward the polarized electrodes to concentrate the contaminants for subsequent removal and ex-situ treatment. Removal of contaminants at the electrode may be accomplished by several means among which are: electroplating at the electrode; precipitation or co-precipitation at the electrode; pumping of water near the electrode; or complexing with ion exchange resins. Enhanced removal is widely used on remediation of soils contaminated metals. "Treatment without Removal" is achieved by electro-osmotic transport of contaminants through treatment zones placed between electrodes. The polarity of the electrodes is reversed periodically, which reverses the direction of the contaminants back and forth through treatment zones. The frequency with which electrode polarity is reversed is determined by the rate of transport of contaminants through the soil. This approach can be used on in-situ remediation of soils contaminated with organic species.

Applicability

Targeted contaminants for electrokinetics are heavy metals, anions, and polar organics in soil, mud, sludge, and marine dredging. Concentrations that can be treated range from a few parts per million (ppm) to tens of thousands ppm. Electrokinetics is most applicable in low permeability soils. Such soils are typically saturated and partially saturated clays and silt-clay mixtures, and are not readily drained.

Limitations

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

- Effectiveness is sharply reduced for wastes with a moisture content of less than 10 percent. Maximum effectiveness occurs if the moisture content is between 14 and 18 percent.
- The presence of buried metallic or insulating material can induce variability in the electrical conductivity of the soil, therefore, the natural geologic spatial variability should be delineated. Additionally, deposits that exhibit very high electrical conductivity, such as ore deposits, cause the technique to be inefficient.
- Inert electrodes, such as carbon, graphite, or platinum, must be used so that no residue will be introduced into the treated soil mass. Metallic electrodes may dissolve as a result of electrolysis and introduce corrosive products into the soil mass.
- Electrokinetics is most effective in clays because of the negative surface charge of clay particles. However, the surface charge of the clay is altered by both changes in the pH of the pore fluid and the adsorption of contaminants. Extreme pH at the electrodes and reduction-oxidation changes induced by the process electrode reactions many inhibit ER's effectiveness, although acidic conditions (i.e., low pH) may help to remove metals.
- Oxidation/reduction reactions can form undesirable products (e.g., chlorine gas).

Costs

Costs will vary with the amount of soil to be treated, the conductivity of the soil, the type of contaminant, the spacing of electrodes, and the type of process design employed. Ongoing pilot-scale studies using "real-world" soils indicate that the energy expenditures in extraction of metals from soils may be 500 kWh per cubic meter or more at electrode spacing of 1.0m to 1.5m. Direct costs estimates of about $15 per cubic meter for a suggested energy expenditure of $0.03 per kilowatt hours, together with the cost of enhancement, could result in direct costs of $50 per cubic meter ($40 per cubic yard) or more. If no other efficient in situ technology were available to remediate fine-grained and heterogeneous subsurface deposits contaminated with metals, this technique would remain potentially competitive.

Site Relevance

This technique is most effective in clays and may have some direct applications if coupled with RFH. However, the presence of metallic subsurface structures and extreme pH conditions may inhibit ER effectiveness. If site conditions allow, ER could be used to help move the contaminants to an area where they can be easily targeted for remediation. This technology may be relevant at certain AOC's at the Siberia Area and will be considered further.

Soil Vapor Extraction

Description

Soil vapor extraction (SVE) is an in situ unsaturated (vadose) zone soil remediation technology in which a vacuum is applied to the soil to induce the controlled flow of air and remove volatile and some semi-volatile contaminants from the soil. The gas leaving the soil may be treated to recover or destroy the contaminants, depending on local and state air discharge regulations. Vertical extraction vents are typically used at depths of 1.5 meters (5 feet) or greater and have been successfully applied as deep as 91 meters (300 feet). Horizontal extraction vents (installed in trenches or horizontal borings) can be used as warranted by contaminant zone geometry, drill rig access, or other site-specific factors.

For the soil surface, geomembrane covers are often placed over soil surface to prevent short-circuiting and to increase the radius of influence of the wells. Ground water depression pumps may be used to reduce ground water upwelling induced by the vacuum or to increase the depth of the vadose zone. Air injection is effective for facilitating extraction of deep contamination, contamination in low permeability soils, and contamination in the saturated zone. The duration of operation and maintenance for in situ SVE is typically medium- to long-term.

Applicability

The target contaminant groups for in situ SVE are VOCs and some petroleum hydrocarbons. The technology is typically applicable only to volatile compounds with a Henry's law constant greater than 0.01 or a vapor pressure greater than 0.5 mm Hg (0.02 inches Hg). Other factors, such as the moisture content, organic content, and air permeability of the soil, will also affect in situ SVE's effectiveness. In situ SVE will not remove heavy oils, metals, PCBs, or dioxins. Because the process involves the continuous flow of air through the soil, however, it often promotes the in situ biodegradation of low-volatility organic compounds that may be present.

Limitations

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

- Soil that has a high percentage of fines and a high degree of saturation will require higher vacuums (increasing costs) and/or hindering the operation of the in situ SVE system.
- Large screened intervals are required in extraction wells for soil with highly variable permeabilities or stratification, which otherwise may result in uneven delivery of gas flow from the contaminated regions.
- Soil that has high organic content or is extremely dry has a high sorption capacity of VOCs, which results in reduced removal rates.
- Exhaust air from in situ SVE system may require treatment to eliminate possible harm to the public and the environment.
- As a result of off-gas treatment, residual liquids may require treatment/disposal. Spent activated carbon will definitely require regeneration or disposal.
- SVE is not effective in the saturated zone; however, lowering the water table can expose more media to SVE (this may address concerns regarding LNAPLs).

Costs

The cost of in situ SVE is site-specific, depending on the size of the site, the nature and amount of contamination, and the hydrogeological setting (EPA, July 1989). These factors affect the number of wells, the blower capacity and vacuum level required, and the length of time required to remediate the site. A requirement for off-gas treatment adds significantly to the cost. Water is also frequently extracted during the process and usually requires treatment prior to disposal, further adding to the cost. Cost estimates for in situ SVE range between \$20 and \$140 per cubic yard of soil. Pilot testing typically exceeds \$10,000.

Site Relevance

Physical site characteristics such as low permeability soils and a very shallow water table, as well as the semi-volatile nature of the primary contaminants of concern, make SVE an inappropriate stand-alone option for this site.

Thermally Enhanced Soil Vapor Extraction

Description

Thermally enhanced SVE is a full-scale technology that uses electrical resistance/electromagnetic/fiber optic/radio frequency heating or hot-air/steam injection to increase the volatilization rate of semi-volatiles and facilitate extraction. The process is otherwise similar to standard SVE systems, but requires heat resistant extraction wells. Thermally enhanced SVE is normally a short- to medium-term technology.

Electrical Resistance Heating

Electrical resistance heating uses an electrical current to heat less permeable soils such as clays and fine-grained sediments so that water and contaminants trapped in these relatively conductive regions are vaporized and ready for vacuum extraction. Electrodes are placed directly into the less permeable soil matrix and activated so that electrical current passes through the soil, creating a resistance that then heats the soil. The heat dries out the soil causing it to fracture. These fractures make the soil more permeable allowing the use of SVE to remove the contaminants. The heat created by electrical resistance heating also forces trapped liquids to vaporize and move to the steam zone for removal by SVE. Six-phase soil heating (SPSH) is a typical electrical resistance heating which uses low-frequency electricity delivered to six electrodes in a circular array to heat soils. With SPSH, the temperature of the soil and contaminant is increased, thereby increasing the contaminant's vapor pressure and its removal rate. SPSH also creates an in situ source of steam to strip contaminants from soil.

Radio Frequency/Electromagnetic Heating

Radio frequency heating (RFH) is an in situ process that uses electromagnetic energy to heat soils and enhances soil vapor extraction (SVE). RFH technique heats a discrete volume of soil using rows of vertical electrodes embedded in soil (or other media). Heated soil volumes are bounded by two rows of ground electrodes with energy applied to a third row midway between the ground rows. The three rows act as a buried triplate capacitor. When energy is applied to the electrode array, heating begins at the top center and proceeds vertically downward and laterally outward through the soil volume. The technique can heat soils to over 300 °C.

RFH enhances SVE in four ways:

- Contaminant vapor pressure and diffusivity are increased by heating,
- The soil permeability is increased by drying,
- An increase in the volatility of the contaminant from in situ steam stripping by the water vapor,
- A decrease in the viscosity which improves mobility.

The technology is self-limiting; as the soil heats and dries, current will stop flowing. Extracted vapor can then be treated by a variety of existing technologies, such as granular activated carbon or incineration.

Hot Air Injection

Hot air or steam is injected below the contaminated zone to heat up contaminated soil. The heating enhances the release of contaminants from the soil matrix. Some VOCs and SVOCs are stripped from contaminated zone and brought to the surface through soil vapor extraction.

Applicability

High moisture content is a limitation of standard SVE that thermal enhancement may help overcome. Heating, especially radio frequency heating and electrical resistance heating can improve air flow in high moisture soils by evaporating water. The system is designed to treat SVOCs but will consequently treat VOCs. Thermally enhanced SVE technologies also are effective in treating some pesticides and fuels, depending on the temperatures achieved by the system. After application of this process, subsurface conditions are excellent for biodegradation of residual contaminants.

Limitations

The following factors may limit the applicability and effectiveness of the process:

- Debris or other large objects buried in the media can cause operating difficulties.
- Performance in extracting certain contaminants varies depending upon the maximum temperature achieved in the process selected.
- Soil that is tight or has high moisture content has a reduced permeability to air, hindering the operation of thermally enhanced SVE and requiring more energy input to increase vacuum and temperature.
- Soil with highly variable permeabilities may result in uneven delivery of gas flow to the contaminated regions.
- Soil that has a high organic content has a high sorption capacity of VOCs, which results in reduced removal rates.
- Air emissions may need to be regulated to eliminate possible harm to the public and the environment. Air treatment and permitting will increase project costs.
- Residual liquids and spent activated carbon may require further treatment.
- Thermally enhanced SVE is not effective in the saturated zone; however, lowering the aquifer can expose more media to SVE (this may address concerns regarding LNAPLs).
- Hot air injection has limitations due to low heat capacity of air.

Costs

Available data indicate the overall cost for thermally enhanced SVE systems is approximately $35 to $150 per cubic yard. Pilot testing typically exceeds $10,000.

Site Relevance

Low permeability soils and a shallow water table would normally remove the possibility of using SVE at this site. However, if coupled with the appropriate thermal enhancement method, it may be a viable option. Of the three methods described above, electrical resistance heating (ERH) and radio frequency heating (RFH), both have the ability to increase soil permeability and improve the effectiveness of the SVE process. Unfortunately though, subsurface utilities and structures can become electrically charged when using electrical thermal enhancement methods. This could present a safety problem at this site and therefore, may not be appropriate. Alternately, RFH is a safe method of enhancement and may be applicable here. RFH has the ability to convert water from a liquid phase to a vapor phase by heating the subsurface to very high temperatures. As the steam is generated it creates micro-fractures in the subsoil and increases soil permeability. Additionally, high temperatures in the subsoil will cause contaminants to volatize and desiccation in the vadose zone. This may allow for horizontal extraction wells to be installed in the vadose zone. This technology may be relevant at this site and will be considered further.

Cap

Description

Caps can be used to:

- Minimize exposure on the surface of the waste facility or contaminated area.
- Prevent vertical infiltration of water into wastes that would create contaminated leachate.
- Contain waste while treatment is being applied.

- Control gas emissions from underlying waste.
- Create a land surface that can support vegetation and/or be used for other purposes.

Capping is a common form of remediation because it is generally less expensive than other technologies and effectively manages the human and ecological risks associated with a remediation site. The design of caps is site specific and depends on the intended functions of the system. Caps can range from a one-layer system of vegetated soil to a complex multi-layer system of soils and geosynthetics. In general, less complex systems are required in dry climates and more complex systems are required in wet climates. The material used in the construction of caps include low-permeability and high-permeability soils and low-permeability geosynthetic products. The low-permeability materials divert water and prevent its passage into the waste. The high permeability materials carry water away that percolates into the cap. Other materials may be used to increase slope stability.

The most critical components of a cap are the barrier layer and the drainage layer. The barrier layer can be low-permeability soil (clay) and/or geosynthetic clay liners (GCLs). A flexible geomembrane liner is placed on top of the barrier layer. Geomembranes are usually supplied in large rolls and are available in several thickness (20 to 140 mil), widths (15 to 100 ft), and lengths (180 to 840 ft). The candidate list of polymers commonly used is lengthy, which includes polyvinyl chloride (PVC), polyethylenes of various densities, reinforced chlorosulfonated polyethylene (CSPE-R), polypropylene, ethylene interpolymer alloy (EIA), and many newcomers. Soils used as barrier materials generally are clays that are compacted to a hydraulic conductivity no greater than 1 x 10-6 cm/sec. Compacted soil barriers are generally installed in 6-inch minimum lifts to achieve a thickness of 2 feet or more. A composite barrier uses both soil and a geomembrane, taking advantage of the properties of each. The geomembrane is essentially impermeable, but, if it develops a leak, the soil component prevents significant leakage into the underlying waste.

For facilities on top of putrescible wastes, the collection and control of methane and carbon dioxide, potent greenhouse gases, must be part of facility design and operation.

Asphalt/Concrete Cap

Effective single-layer caps can be composed of concrete or bituminous asphalt. They can be used to form a surface barrier between contaminants and the environment. An asphalt/concrete cap would also reduce groundwater infiltration and subsequently contaminant leaching into an adjacent aquifer.

RCRA Subtitle C Cap

The RCRA C multilayered cap is a baseline design that is suggested for use in RCRA hazardous waste applications. These caps generally consist of an upper vegetative (topsoil) layer, a drainage layer, and a low permeability layer which consists of a synthetic liner over 2 feet of compacted clay. The compacted clay liners are effective if they retain a certain moisture content but are susceptible to cracking if the clay material is desiccated. As a result alternate cap designs are usually considered for arid environments.

RCRA Subtitle D Cap

RCRA Subtitle D requirements are for non-hazardous waste landfills. The design of a cover for a RCRA Subtitle D facility is generally a function of the bottom liner system or natural subsoil's present.

The cover must meet the following specifications:

The material must have a permeability no greater than 1 x 10-5 cm/s, or equivalent permeability of any bottom liner or natural subsoil's present, whichever is less. The infiltration layer must contain at least 45 cm of earthen material. The erosion control layer must be at least 15 cm of earthen material capable of sustaining native plant growth.

Alternative design can be considered, but must be of equivalent performance as the specifications outlined above. All covers should be designed to prevent the "bathtub" effect. The bathtub effect occurs when a more permeable cover is placed over a less permeable bottom liner or natural subsoil and then fills up like a bathtub.

Applicability

Caps may be temporary or final. Temporary caps can be installed before final closure to minimize generation of leachate until a better remedy is selected. They are usually used to minimize infiltration when the underlying waste mass is undergoing settling. A more stable base will thus be provided for the final cover, reducing the cost of the post-closure maintenance. Caps also may be applied to waste masses that are so large that other treatment is impractical. At mining sites for example, caps can be used to minimize the infiltration of water to contaminated tailings piles and to provide a suitable base for the establishment of vegetation. In conjunction with water diversion and detention structures, landfill caps may be designed to route surface water away from the waste area while minimizing erosion.

Limitations

Capping does not lessen toxicity, mobility, or volume of hazardous wastes, but does mitigate migration. Caps are most effective where most of the underlying waste is above the water table. A cap, by itself, cannot prevent the horizontal flow of ground water through the waste, only the vertical entry of water into the waste. In many cases caps are used in conjunction with vertical walls to minimize horizontal flow and migration. The effective life of landfill components (including cap) can be extended by long-term inspection and maintenance. Vegetation must be controlled. Grass can be used for erosion control, however deep root penetration must be eliminated from the cap area. In addition, precautions must be taken to assume that the integrity of the cap is not compromised by land use activities.

Costs

Caps are generally a cost-effective way to manage the human health and ecological risks effectively. Rough industry costs are $175k/acre for RCRA Subtitle D, and $225k/acre for RCRA Subtitle C. Other caps (such as select fill) may cost as low as $75K/acre. For cost comparison purposes with other technologies it is assumed that a capping option would limit the exposure pathways of at least a one-foot thick layer of contaminated soil per unit area capped such that the need for further active remediation is eliminated. The subsequent costs could then be less than $50 per cubic yard of soil remediated using this technique.

Site Relevance

A cap is a cost effective measure that can reduce human health risks by limiting the exposure pathways. A cap can offer the opportunity to contain and limit exposure to vadose contaminants while a long term remedial measure is being applied to the contaminated subsoils. This technology may be relevant to the site and will be considered further.

EX-SITU TECHNOLOGIES

Excavation, Retrieval, and Off-Site Disposal

Description

Contaminated material is removed and transported to permitted off-site treatment and/or disposal facilities. Some pretreatment of the contaminated media may be required in order to meet land disposal restrictions.

Applicability

Excavation and off-site disposal is applicable to the complete range of contaminant groups with no particular target group. Excavation and off-site by relocating the waste to a different (and presumably safer) site.

Limitations

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

- Generation of fugitive emissions and odors may be a problem during operations.
- The distance from the contaminated site to the nearest disposal facility with the required permit(s) will affect cost.
- Depth and composition of the media requiring excavation must be considered.
- Transportation of the soil through populated areas may affect community acceptability.

Costs

Cost estimates for excavation and disposal range from $195 (Subtitle D landfill) to $315 (Subtitle C Landfill) per cubic yard, depending on the nature of the contaminated materials and methods of excavation. These estimates include excavation/removal, transportation, and disposal at a permitted facility, as well as backfilling the excavation.

Additional cost of treatment at the disposal facility may also be required. Excavation and off-site disposal is a relatively simple process, with proven procedures. It is a labor-intensive practice with little potential for further automation. Additional costs may include soil characterization and treatment to meet land ban requirements, dewatering operations, shoring, and utility relocation.

Site Relevance

Excavation and removal is a viable short term option, however, it presents a liability at the disposal facility. Costs are generally high but the contamination is removed from the site quickly and permanently. This remediation technique will be retained for further evaluation.

Biopiles

Description

Biopile treatment is a full-scale technology in which excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration. It is used to reduce concentrations of petroleum constituents in excavated soils through the use of biodegradation. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.

The treatment area will generally be covered or contained with an impermeable liner to minimize the risk of contaminants leaching into an uncontaminated soil. The drainage itself may be treated in a bioreactor before recycling. Vendors have developed proprietary nutrient and additive formulations and methods for incorporating the formulation into the soil to stimulate biodegradation. The formulations are usually modified for site-specific conditions.

Soil piles and cells commonly have an air distribution system buried under the soil to pass air through the soil either by vacuum or by positive pressure. The soil piles in this case can be up to 20 feet high (generally not recommended, 2-3 meters maximum). Soil piles may be covered with plastic to control runoff, evaporation, and volatilization and to promote solar heating. If there are VOCs in the soil that will volatilize into the air stream, the air leaving the soil may be treated to remove or destroy the VOCs before they are discharged to the atmosphere.

Biopile is a short-term technology. Duration of operation and maintenance may last a few weeks to several months. Treatment alternatives include static processes such as: prepared treatment-beds, biotreatment cells, soil piles, and composting.

Applicability

Biopile treatment has been applied to treatment of nonhalogenated VOCs and fuel hydrocarbons. Halogenated VOCs, SVOCs, and pesticides also can be treated, but the process effectiveness will vary and may be applicable only to some compounds within these contaminant groups.

Limitations

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

- Excavation of contaminated soils is required.
- Treatability testing should be conducted to determine the biodegradability of contaminants and appropriate oxygenation and nutrient loading rates.
- Solid phase processes have variable effectiveness for halogenated compounds.
- Similar batch sizes require more time to complete cleanup than slurry phase processes.
- Static treatment processes may result in less uniform treatment than processes that involve periodic mixing.

Costs

Costs are dependent on the contaminant, procedure to be used, need for additional pre- and post-treatment, and need for air emission control equipment. Biopiles are relatively simple and require few personnel for operation and maintenance. Typical costs with a prepared bed and liner are $25 to $200 per cubic yard.

Site Relevance

Bio-degradation has already been verified to be occurring onsite based on data generated from on-site soil sampling and aerobic bio-treatability studies. Excavation of vadose soils for the purpose of bio-treatability may not be cost effective. In addition, there may be restrictions on the availability of sufficient surface area to construct a biopile in the Siberia Area. However, this technology would allow the relocation of the contaminated soils away from residential areas adjacent to the site. This would minimize nuisance odors for off-site residents during mixing/aeration events. This technology may be relevant to this site and will be considered further.

Incineration

Description

High temperatures, 870 to 1,200 °C (1,400 to 2,200 °F), are used to volatilize and combust (in the presence of oxygen) halogenated and other refractory organics in hazardous wastes. Often auxiliary fuels are employed to initiate and sustain combustion. The destruction and removal efficiency (DRE) for properly operated incinerators exceeds the 99.99% requirement for hazardous waste and can be operated to meet the 99.9999% requirement for PCBs and dioxins. Off gases and combustion residuals generally require treatment.

Circulating Bed Combustor (CBC)

Circulating bed combustor (CBC) uses high velocity air to entrain circulating solids and create a highly turbulent combustion zone that destroys toxic hydrocarbons. The CBC operates at lower temperatures than conventional incinerators (1,450 to 1,600 °F). The CBC's high turbulence produces a uniform temperature around the combustion chamber and hot cyclone. The CBC also completely mixes the waste material during combustion. Effective mixing and low combustion temperature reduce operating costs and potential emissions of such gases as nitrogen oxide (NOx) and carbon monoxide (CO).

Fluidized Bed

The circulating fluidized bed (CFB), uses high-velocity air to circulate and suspend the waste particles in a combustion loop and operates at temperatures up to 870 °F (1,600 °F). Another experimental unit, the infrared unit uses electrical resistance heating elements or indirect-fired radiant U-tubes to heat material passing through the chamber on a conveyor belt and operates at temperatures up to 870 °F (1,600 °F).

Infrared Combustion

The infrared combustion technology is a mobile thermal processing system that uses electrically powered silicon carbide rods to heat organic wastes to combustion temperatures. Waste is fed into the primary chamber and exposed to infrared radiant heat (up to 1,850 °F) provided by silicon carbide rods above the conveyor belt. A blower delivers air to selected locations along the belt to control the oxidation rate of the waste feed. Any remaining combustibles are incinerated in an afterburner.

Rotary Kilns

Commercial incinerator designs are rotary kilns, equipped with an afterburner, a quench, and an air pollution control system. The rotary kiln is a refractory-lined, slightly-inclined, rotating cylinder that serves as a combustion chamber and operates at temperatures up to 980 °F (1,800 °F).

Incinerator off-gas requires treatment by an air pollution-control system to remove particulates, neutralize, and remove acid gases (HCl, NOx, and SOx). Baghouses, venturi scrubbers, and wet electrostatic precipitators remove particulates; packed-bed scrubbers and spray driers remove acid gases.

Incineration, primarily off-site, has been selected or used as the remedial action at more than 150 Superfund sites. Incineration is subject to a series of technology-specific regulations, including the following federal requirements: CAA (air emissions), TSCA (PCB treatment and disposal), RCRA (hazardous waste generation, treatment, storage, and disposal), NPDES (discharge to surface waters), and NCA (noise). The duration of incineration technology ranges from short- to long-term.

Applicability

Incineration is used to remediate soils contaminated with explosives and hazardous wastes, particularly chlorinated hydrocarbons, PCBs, and dioxins.

Limitations

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

- There are specific feed size and materials handling requirements that can impact applicability or cost at specific sites.
- Dewatering may be necessary to achieve acceptable soil moisture content levels.
- Heavy metals can produce a bottom ash that requires stabilization.
- Volatile heavy metals, including lead, cadmium, mercury, and arsenic, leave the combustion unit with the flue gases and require the installation of gas cleaning systems for removal.

Costs

Soil treatment costs at off-site incinerators range from $200 to $1,000 per ton of soil, including all project costs. Mobile units that can be operated on-site will reduce soil transportation and backfilling costs, however additional mobilization/demobilization and permitting costs will be incurred.

Site Relevance

The use of incineration would be cost prohibitive for this site. Given the site contaminants it would not be an appropriate treatment method. This technique is not relevant to this site and will not be evaluated further.

Thermal Desorption

Description

Thermal desorption is a physical separation process and is not designed to destroy organics. Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system. The bed temperatures and residence times designed into these systems will volatilize selected contaminants but will typically not oxidize them.

Two common thermal desorption designs are the rotary dryer and thermal screw. Rotary dryers are horizontal cylinders that can be indirect- or direct-fired. The dryer is normally inclined and rotated. For the thermal screw units, screw conveyors or hollow augers are used to transport the medium through an enclosed trough. Hot oil or steam circulates through the auger to indirectly heat the medium. All thermal desorption systems require treatment of the off-gas to remove particulates and contaminants. Particulates are removed by conventional particulate removal equipment, such as wet scrubbers or fabric filters. Contaminants are removed through condensation followed by carbon adsorption, or they are destroyed in a secondary combustion chamber or a catalytic oxidizer. Most of these units are transportable.

Three types of thermal desorption are available and briefly described as following:

1. Direct Fired: Fire is applied directly upon the surface of contaminated media. The main purpose of the fire is to desorb contaminants from the soil though some contaminants may be thermally oxidized.

2. Indirect Fired: A direct-fired rotary dryer heats an air stream which, by direct contact, desorbs water and organic contaminants from the soil. The Low Temperature Thermal Aeration (LTTA®) developed by Canonie Environmental Services Corporation is a good example of indirect fired system which has been successfully used to remove DDT family compounds from soil.

3. Indirect Heated: An externally fired rotary dryer volatilizes the water and organics from the contaminated media into an inert carrier gas stream. The carrier gas is later treated to remove or recover the contaminants. XTRAX™ thermal Desorption System is a process using indirect heated desorption

followed by a high-energy scrubber gas treatment, which successfully removed >99% of PCB from contaminated soil.

Based on the operating temperature of the desorber, thermal desorption processes can be categorized into two groups: high temperature thermal desorption (HTTD) and low temperature thermal desorption (LTTD).

High Temperature Thermal Desorption (HTTD)

HTTD is a full-scale technology in which wastes are heated to 320 to 560 °C (600 to 1,000 °F). HTTD is frequently used in combination with incineration, solidification/stabilization, or dechlorination, depending upon site-specific conditions. The technology has proven it can produce a final contaminant concentration level below 5 mg/kg for the target contaminants identified.

Low Temperature Thermal Desorption (LTTD)

In LTTD, wastes are heated to between 90 and 320 °C (200 to 600 °F). LTTD is a full-scale technology that has been proven successful for remediating petroleum hydrocarbon contamination in all types of soil. Contaminant destruction efficiencies in the afterburners of these units are greater than 95%. The same equipment could probably meet stricter requirements with minor modifications, if necessary. Decontaminated soil retains its physical properties. Unless being heated to the higher end of the LTTD temperature range, organic components in the soil are not damaged, which enables treated soil to retain the ability to support future biological activity.

Applicability

Thermal desorption systems have varying degrees of effectiveness against the full spectrum of organic contaminants. The target contaminant groups for LTTD systems are nonhalogenated VOCs and fuels. The technology can be used to treat SVOCs at reduced effectiveness. The target contaminants for HTTD are SVOCs, PAHs, PCBs, and pesticides; however, VOCs and fuels also may be treated, but treatment may be less cost-effective. Volatile metals may be removed by HTTD systems.

Limitations

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

- There are specific particle size and materials handling requirements that can impact applicability or cost at specific sites.
- Dewatering may be necessary to achieve acceptable soil moisture content levels.
- Highly abrasive feed potentially can damage the processor unit.
- Heavy metals in the feed may produce a treated solid residue that requires stabilization.
- Clay and silty soils and high humic content soils increase reaction time as a result of binding of contaminants.

Costs

Rates charged to remediate petroleum hydrocarbon contaminated soil range from $75 to $450 per cubic yard of soil. These costs include excavation, treatment and backfill of the contaminated soils. Unit transportation and setup costs are typically $5 to $8 per cubic yard, seldom exceeding a mobilization cost of $200,000.

Site Relevance

There are specific particle size and materials handling requirements that can impact applicability or cost at this site. De-watering may be necessary to achieve acceptable soil moisture content levels and low permeability soils increase reaction time as a result of binding of contaminants. However, given the site contaminants, and the potentially large volumes of soil to be treated, this technique may be appropriate and will be evaluated further.

5.2 Preliminary Screening For Groundwater Media

INSITU TECHNOLOGIES

Natural Attenuation

Description

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,
- For the persistent or conserved contaminants, ensured containment during and after natural attenuation.

Applicability

Target contaminants for natural attenuation are VOCs and 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.

Limitations

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.

Costs

There are costs for modeling contamination degradation rates to determine whether natural attenuation is a feasible remedial alternative. Additional costs are for appropriate containment, surface and subsurface sampling and sample analysis (potentially extensive) to determine the extent of contamination and confirm contaminant degradation rates and cleanup status. Skilled labor hours are required to conduct the modeling, sampling, and analysis. O&M costs would be required for monitoring to confirm that contaminant migration has not occurred.

Site Relevance

A conceptual site model and long-term monitoring program is already in place. Additionally, bench-scale treatability studies have indicated that TPH's and PAH's are being readily degraded aerobically in onsite soils and may be biodegraded in groundwater. Therefore, additional costs for evaluating and confirming natural attenuation would be relatively low. This alternative will be considered further.

Enhanced Bioremediation

Description

Enhanced bioremediation is a process 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, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials. Aerobic microorganisms, in the presence of sufficient oxygen (aerobic conditions), and other nutrient elements, microorganisms will ultimately convert many organic contaminants to carbon dioxide, water, and microbial cell mass. Anaerobic microorganisms, in the absence of oxygen (anaerobic conditions), the organic contaminants will be ultimately metabolized to methane, limited amounts of carbon dioxide, and trace amounts of hydrogen gas. Under sulfate-reduction conditions, sulfate is converted to sulfide or elemental sulfur, and under nitrate-reduction conditions, dinitrogen gas is ultimately produced. 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 vinyl chloride. To avoid such problems, most bioremediation projects are conducted in situ. Vinyl chloride can easily be broken down further if aerobic conditions are created.

Applicability

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. These techniques, while still largely experimental, show considerable promise of stabilizing or removing inorganics from soil.

Limitations

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

- Preferential colonization by microbes may occur causing clogging of nutrient and water injection wells.
- 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 heterogeneous subsurface environments because of oxygen (or other electron acceptor) transfer limitations.
- High concentrations of heavy metals, highly chlorinated organics, long chain hydrocarbons, or inorganic salts are likely to be toxic to microorganisms.
- Bioremediation slows at low temperatures.

Many of the above factors can be controlled with proper attention to good engineering practice.

Costs

Typical costs for enhanced bioremediation range from $20 to $80 per cubic yard of saturated soil. Variables affecting the cost are the nature, extent, and depth of the contaminants, and use of bio-augmentation.

Site Relevance

Low permeability subsoils may prohibit contaminant-microorganism contact. Therefore, bio-enhancement (e.g., heat, nutrients, oxygen, physical mixing) will be necessary to improve soil permeability and increase the potential for the reduction of the PAH's within the saturated soil/groundwater. This technology is relevant for the Siberia Area and will be considered further.

Chemical Reduction/Oxidation

Description

Reduction/oxidation (Redox) reactions chemically convert hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. Redox reactions involve the transfer of electrons from one compound to another. Specifically, one reactant is oxidized (loses electrons) and one is reduced (gains electrons). The oxidizing agents most commonly used for treatment of hazardous contaminants are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide. Enhanced chemical redox systems are now frequently being used to treat contaminated groundwater and saturated soils.

Applicability

The technology can be used to target halogenated and nonhalogenated VOCs and SVOCs, petroleum hydrocarbons, and pesticides.

Limitations

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

- Incomplete oxidation or formation of intermediate contaminants may occur depending upon the contaminants and oxidizing agents used.
- The process is not cost-effective for high contaminant concentrations because of the large amounts of oxidizing agent required.
- 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.
- Oil and grease in the media should be minimized to optimize process efficiency.

Costs

Estimated costs range from $150 to $500 per saturated cubic yard.

Site Relevance

Although the technique can prove to be costly, it has the ability to remove contaminants in groundwater over a very short period of time. Low permeability soils present difficulties in efficiently delivering agents to contaminated zones and effectively allowing agent/contaminant contact. The technique may have direct applications at this site, especially in discrete zones with elevated organic contaminant concentrations. This technique will be evaluated further for the remediation of hot spots in the saturated zone.

Electrokinetic Separation

Description

The principle of electrokinetic remediation (ER) relies upon application of a low-intensity direct current through the soil between ceramic electrodes that are divided into a cathode array and an anode array. This mobilizes charged species, causing ions and water to move toward the electrodes. Metal ions, ammonium ions, and positively charged organic compounds move toward the cathode. Anions such as chloride, cyanide, fluoride, nitrate, and negatively charged organic compounds move toward the anode. The current creates an acid front at the anode and a base front at the cathode. This generation of acidic condition in situ may help to mobilize sorbed metal contaminants for transport to the collection system at the cathode.

The two primary mechanisms transport contaminants through the soil towards one or the other electrodes: electro-migration and electro-osmosis. In electro-migration, charged particles are transported through the substrate. In contrast, electro-osmosis is the movement of a liquid containing ions relative to a stationary charged surface. Of the two, electro-migration is the main mechanism for the ER process. The direction and rate of movement of an ionic species will depend on its charge, both in magnitude and polarity, as well as the magnitude of the electro-osmosis induced flow velocity. Non-ionic species, both inorganic and organic, will also be transported along with the electro-osmosis induced water flow.

Two approaches are taken during electrokinetic remediation: "Enhanced Removal" and "Treatment without Removal". "Enhanced Removal" is achieved by electrokinetic transport of contaminants toward the polarized electrodes to concentrate the contaminants for subsequent removal and ex-situ treatment. Removal of contaminants at the electrode may be accomplished by several means among which are: electroplating at the electrode; precipitation or co-precipitation at the electrode; pumping of water near the electrode; or complexing with ion exchange resins. Enhanced removal is widely used on remediation of soils contaminated metals. "Treatment without Removal" is achieved by electro-osmotic transport of contaminants through treatment zones placed between electrodes. The polarity of the electrodes is reversed periodically, which reverses the direction of the contaminants back and forth through treatment zones. The frequency with which electrode polarity is reversed is determined by the rate of transport of contaminants through the soil. This approach can be used on in-situ remediation of soils contaminated with organic species.

Applicability

Targeted contaminants for electrokinetics are heavy metals, anions, and polar organics in soil, mud, sludge, and marine dredging. Concentrations that can be treated range from a few parts per million (ppm) to tens of thousands ppm. Electrokinetics is most applicable in low permeability soils. Such soils are typically saturated and partially saturated clays and silt-clay mixtures, and are not readily drained.

Limitations

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

- Effectiveness is sharply reduced for wastes with a moisture content of less than 10 percent. Maximum effectiveness occurs if the moisture content is between 14 and 18 percent.
- The presence of buried metallic or insulating material can induce variability in the electrical conductivity of the soil, therefore, the natural geologic spatial variability should be delineated. Additionally, deposits that exhibit very high electrical conductivity, such as ore deposits, cause the technique to be inefficient.
- Inert electrodes, such as carbon, graphite, or platinum, must be used so that no residue will be introduced into the treated soil mass. Metallic electrodes may dissolve as a result of electrolysis and introduce corrosive products into the soil mass.
- Electrokinetics is most effective in clays because of the negative surface charge of clay particles. However, the surface charge of the clay is altered by both changes in the pH of the pore fluid and the adsorption of contaminants.

Extreme pH at the electrodes and reduction-oxidation changes induced by the process electrode reactions many inhibit ER's effectiveness, although acidic conditions (i.e., low pH) may help to remove metals.

- Oxidation/reduction reactions can form undesirable products (e.g., chlorine gas).

Costs

Costs will vary with the amount of soil to be treated, the conductivity of the soil, the type of contaminant, the spacing of electrodes, and the type of process design employed. Ongoing pilot-scale studies using "real-world" soils indicate that the energy expenditures in extraction of metals from soils may be 500 kWh per cubic meter or more at electrode spacing of 1.0m to 1.5m. Direct costs estimates of about $15 per cubic meter for a suggested energy expenditure of $0.03 per kilowatt hours, together with the cost of enhancement, could result in direct costs of $50 per cubic meter ($40 per cubic yard) or more. If no other efficient in situ technology were available to remediate fine-grained and heterogeneous subsurface deposits contaminated with metals, this technique would remain potentially competitive.

Site Relevance

This technique is most effective in clays and may have some direct applications if coupled with RFH. However, the presence of metallic subsurface structures and extreme pH conditions may inhibit ER effectiveness. If site conditions allow, ER could be used to help the contaminants to an area where they can be easily targeted for remediation. This technology may be relevant at certain AOC's at the Siberia Area and will be considered further.

Air Sparging

Description

Air sparging is an in situ technology in which air is injected through a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil column, creating an underground stripper that removes contaminants by volatilization. This injected air helps to flush (bubble) the contaminants up into the unsaturated zone where a vapor extraction system is usually implemented in conjunction with air sparging to remove the generated vapor phase contamination. This technology is designed to operate at high flow rates to maintain increased contact between groundwater and soil and strip more ground water by sparging.

Oxygen added to contaminated ground water and vadose zone soils can also enhance biodegradation of contaminants below and above the water table. Air sparging has a medium to long duration that may last, generally, up to a few years.

Applicability

The target contaminant groups for air sparging are VOCs and fuels. Only limited information is available on the process. Methane can be used as an amendment to the sparged air to enhance cometabolism of chlorinated organics.

Limitations

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

- Air flow through the saturated zone may not be uniform, which implies that there can be uncontrolled movement of potentially dangerous vapors.
- Depth of contaminants and specific site geology must be considered.
- Air injection wells must be designed for site-specific conditions. Although the water table is relatively shallow, its seasonal variations may preclude the use of horizontal wells or trenches
- Soil heterogeneity may cause some zones to be relatively unaffected.

Costs

The cost of air sparging is site-specific, depending on the size of the site, the nature and amount of contamination, and the hydrogeological setting. These factors affect the number of wells, the blower capacity and vacuum level required, and the length of time required to remediate the site. A requirement for off-gas treatment adds significantly to the cost. Water is also frequently extracted during the process and usually requires treatment prior to disposal, further adding to the cost. Cost estimates for air sparging systems range from $20 to $140 per saturated cubic yard of soil. Pilot testing typically exceeds $10,000.

Site Relevance

This technique would be effective in removing site contaminants and even potentially enhancing bio-degradation. Unfortunately, the low permeability and heterogeneity of the overburden would restrict uniform air flow through the saturated zone, which implies that there can be uncontrolled movement of potentially dangerous vapors and may cause some zones to be relatively unaffected. Also, if coupled with an SVE system to remove vapors from the subsoil, the water table would have to be lowered. This implies that to effectively utilize this technique additional techniques would have to be implemented to lower the water table and increase soil permeability.

Due to the physical site characteristics (e.g., low permeability and heterogeneity of the soil, shallow water table) as well as the semi-volatile nature of the primary contaminants of concern, air sparging does not appear to be relevant and will not be considered further.

In-Well Stripping

Description

Air is injected into a double screened well, lifting the water in the well and forcing it out the upper screen. Simultaneously, additional water is drawn in the lower screen. Once in the well, some of the VOCs in the contaminated ground water are transferred from the dissolved phase to the vapor phase by air bubbles. The contaminated air rises in the well to the water surface where vapors are drawn off and treated by a soil vapor extraction system. This SVE system, in addition to collecting the vapors from within the well, collects vapors from the surrounding vadose zone. The partially treated ground water is never brought to the surface; it is forced into the unsaturated zone, and the process is repeated as water follows a hydraulic circulation pattern or cell that allows continuous cycling of ground water. As ground water circulates through the treatment system in situ, contaminant concentrations are gradually reduced. In-well air stripping is a pilot-scale technology.

Modifications to the basic in-well stripping process may involve additives injected into the stripping well to enhance biodegradation (e.g., nutrients and electron acceptors). In addition, the area around the well affected by the circulation cell (radius of influence) can be modified through the addition of certain chemicals to allow in situ stabilization of metals originally dissolved in ground water.

The duration of in-well air stripping is short- to long-term, depending contaminant concentrations, Henry's law constants of the contaminants, the radius of influence, the soil characteristics in the vadose zone, and site hydrogeology.

Circulating Wells

Circulating wells (CWs) provide a technique for subsurface remediation by creating a three-dimensional circulation pattern of the ground water. Groundwater is drawn into a well through one screened section and is pumped through the well to a second screened section where it is reintroduced to the aquifer. The flow direction through the well can be specified as either upward or downward to accommodate site-specific conditions. Because ground water is not pumped above ground, pumping costs and permitting issues are reduced and eliminated, respectively. Also, the problems associated with storage and discharge are removed. In addition to ground water treatment, CW systems can provide simultaneous vadose zone treatment in the form of bioventing or soil vapor extraction.

CW systems can provide treatment inside the well, in the aquifer, or a combination of both. For effective in-well treatment, the contaminants must be adequately soluble and mobile so they can be transported by the circulating ground water. Because CW systems provide a wide range of treatment options, they provide some degree of flexibility to a remediation effort.

Applicability

The target contaminant groups for vacuum vapor extraction are halogenated VOCs, SVOCs, and fuels. Variations of the technology may allow for its effectiveness against some nonhalogenated VOCs, SVOCs, pesticides, and inorganics. Typically, in-well air stripping systems are a cost-effective approach for remediating VOC-contaminated ground water at sites with deep water tables because the water does not need to be brought to the surface.

CW systems are most effective at treating sites with volatile contaminants with relatively high aqueous solubility and strong biodegradation potential, e.g., halogenated and non-halogenated VOCs. CWs operate more efficiently with horizontal conductivities greater that 10-3 cm/sec and a ratio of horizontal to vertical conductivities between 3 and 10. A ratio of less than 3 indicates short circulation times and a small radius of influence. If the ratio is greater that 10, the circulation time may be unacceptably long.

Limitations

The following factors may limit the applicability and effectiveness of the process:

- In general, in-well air strippers are more effective at sites containing high concentrations of dissolved contaminants with high Henry's law constants.
- Fouling of the system may occur by infiltrating precipitation containing oxidized constituents.
- Shallow aquifers may limit process effectiveness.
- Effective CW installations require a well-defined contaminant plume to prevent the spreading or smearing of the contamination. They should not be applied to sites containing NAPLs to prevent the possibility of smearing the contaminants.
- CWs are limited to sites with horizontal hydraulic conductivities greater that 10^{-5} cm/sec (preferably 10^{-3} cm/sec) and should not be utilized at sites that have lenses of low-conductivity deposits.
- In well air stripping may not be efficient in sites with strong natural flow patterns.

Costs

Because of the number of variables involved, establishing general costs for In-Well Stripping is difficult. Some representative costs are $8.82 per square foot of plume with capital costs comprising $5.80 per square foot and annual O&M comprising $3.02 per square foot.

Site Relevance

Shallow water table and aquifer conditions may limit process effectiveness, as the vadose zone is not sufficient for well engineering requirements. Also, this system is designed primarily for VOC removal and has limited application for SVOC contaminants. CW's should not be utilized at sites that have low-permeability overburden or fractured bedrock. A good understanding on hydraulic controls is imperative and again, the permeability would have to be improved. This technique would not be cost effective and probably not applicable at this site. In-Well Stripping will not be considered further.

Dual Phase Extraction

Description

Dual-phase extraction (DPE), also known as multi-phase extraction, vacuum-enhanced extraction, or sometimes bioslurping, is a technology that uses a high vacuum system to remove various combinations of contaminated ground water, separate-phase petroleum product, and hydrocarbon vapor from the subsurface. Extracted liquids and vapor are treated and collected for disposal, or re-injected to the subsurface (where permissible under applicable state laws).

In DPE systems for liquid/vapor treatment, a high vacuum system is utilized to remove liquid and gas from low permeability or heterogeneous formations. The vacuum extraction well includes a screened section in the zone of contaminated soils and ground water. It removes contaminants from above and below the water table. The system lowers the water table around the well, exposing more of the formation. Contaminants in the newly exposed vadose zone are then accessible to vapor extraction. Once above ground, the extracted vapors or liquid-phase organics and ground water are separated and treated. DPE for liquid/vapor treatment is generally combined with bioremediation, air sparging, or bioventing when the target contaminants include long-chained hydrocarbons. Use of dual phase extraction with these technologies can shorten the cleanup time at a site. It also can be used with pump-and-treat technologies to recover ground water in higher-yielding aquifers.

The DPE process for undissolved liquid-phase organics, also known as free product recovery, is used primarily in cases where a fuel hydrocarbon lens more than 20 centimeters

(8 inches) thick is floating on the water table. The free product is generally drawn up to the surface by a pumping system. Following recovery, it can be disposed of, re-used directly in an operation not requiring high-purity materials, or purified prior to re-use. Systems may be designed to recover only product, mixed product and water, or separate streams of product and water. Dual phase extraction is a full-scale technology.

Applicability

The target contaminant groups for dual phase extraction are light non-aqueous phase liquids (LNAPLs), VOCs and fuels components. Dual phase vacuum extraction is more effective than SVE for heterogeneous clays and fine sands. However, it is not recommended for lower permeability formations due to the potential to leave isolated lenses of undissolved product in the formation.

Limitations

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

- Site geology and contaminant characteristics/distribution.
- Combination with complementary technologies (e.g., pump-and-treat) may be required to recover ground water from high yielding aquifers.
- Dual phase extraction requires both water treatment and vapor treatment.

Costs

Because of the number of variables involved, establishing general costs for dual phase extraction is difficult. Estimated cost ranges per site are between $85,000 to $500,000 per site. These costs illustrate the relative magnitudes of the various recovery options available, which are typically less than other types of remediation.

Key cost factors for the recovery of free product include waste disposal, potential for sale of recovered product for recycling, on-site equipment rental (e.g., pumps, tanks, treatment systems), installation of permanent equipment, and engineering and testing costs.

Site Relevance

Dual phase vacuum extraction is more effective than SVE for heterogeneous fine-grained soils. However, it is not recommended for lower permeability formations due to the potential to leave isolated lenses of un-dissolved product in the formation. Additionally, SVE cannot be operated onsite due to a limited vadose zone, which further limits the applicability of this technique. The costs associated with implementing this type of system would not only be significant, the system itself would be a long term measure and may not be as effective as many of the other techniques. Therefore, this technique will not be considered further.

Barrier Technologies

Slurry Wall/Vertical Barrier

Description

Slurry walls are used to contain contaminated ground water to prevent the migration of contaminants, divert contaminated ground water from a drinking water intake, divert uncontaminated ground water flow, and/or provide a barrier for a ground water treatment system. Slurry walls consist of a vertically excavated trench that is filled with a slurry. The slurry hydraulically shores the trench to prevent collapse and forms a filter cake to reduce ground water flow. Slurry walls often are used where the waste mass is too large for treatment and where soluble and mobile constituents pose an imminent threat to a source of drinking water. Slurry walls are a full-scale technology that have been used for decades as long-term solutions for controlling seepage. They are often used in conjunction with capping. The technology has demonstrated its effectiveness in containing greater than 95% of the uncontaminated ground water; however, in contaminated ground water applications, specific contaminant types may degrade the slurry wall components and reduce the long-term effectiveness.

Most slurry walls are constructed of a soil, bentonite, and water mixture. The bentonite slurry is used primarily for wall stabilization during trench excavation. A soil-bentonite backfill material is then placed into the trench (displacing the slurry) to create the cutoff wall. Walls of this composition provide a barrier with low permeability and chemical resistance at low cost. Other wall compositions, such as cement, cement/bentonite, pozzolan/bentonite, attapulgite, organically modified bentonite, sheet pile or slurry/geomembrane composite, may be used if greater structural strength is required or if chemical incompatibilities between bentonite and site contaminants exist.

Slurry walls are typically placed at depths up to 30 meters (100 feet) and are generally 0.6 to 1.2 meters (2 to 4 feet) in thickness. Installation depths over 30 m (100 ft) are implementable using clam shell bucket excavation, but the cost per unit area of wall increases by about a factor of three. The most effective application of the slurry wall for site remediation or pollution control is to base (or key) the slurry wall 0.6 to 0.9 meters (2 to 3 feet) into a low permeability layer such as clay or bedrock. This "keying-in" provides for an effective foundation with minimum leakage potential. An alternate configuration for slurry wall installation is a "hanging" wall in which the wall projects into the ground water table to block the movement of lower density or floating contaminants such as oils, fuels, or gases. Hanging walls are used less frequently than keyed-in walls.

Applicability

Slurry walls contain the ground water, thus treating no particular target group of contaminants. They are used to contain contaminated ground water, divert contaminated ground water from drinking water intake, divert uncontaminated ground water flow, and/or provide a barrier for the ground water treatment system.

Limitations

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

- Most of the approaches involve a large amount of heavy construction.
- Installation within competent bedrock may be cost prohibitive.
- The technology only contains contaminants within a specific area.
- Soil-bentonite backfills are not able to withstand attack by strong acids, bases, salt solutions, and some organic chemicals. Other slurry mixtures can be developed to resist specific chemicals.

- There is the potential for the slurry walls to degrade or deteriorate over time.
- Use of this technology does not guarantee that further remediation in the future may not be necessary.

Costs

The cost likely to be incurred in the design and installation of a standard slurry wall, less than 20 feet deep is approximately \$80 yd^3. Costs for a sheet pile wall are approximately \$25 ft^2. Costs for a geo-wall are approximately \$10 ft^2. These costs do not include variable costs required for chemical analyses, feasibility, or compatibility testing. Testing costs depend heavily on site-specific factors.

Factors that have the most significant impact on the final cost of a wall installation include:

- Type, activity, and distribution of contaminants.
- Depth, length, and width of wall.
- Geological and hydrological characteristics.
- Distance from source of materials and equipment.
- Requirements for wall protection and maintenance.
- Type of slurry and backfill used.
- Other site-specific requirements as identified in the initial site assessment (e.g., presence of contaminants, bedrock or debris).
- Planning, permitting, regulatory interaction, and site restoration.

Site Relevance

The use of non-permeable barriers may not be appropriate in the Siberia Area, except in the southwest quadrant. Contaminants directly beneath the substation may be difficult to remediate due to site conditions. A vertical barrier may be appropriate to restrict horizontal movement of the contaminants. However, there are more appropriate remedial options for removing contaminants in the groundwater downgradient of the substation and therefore, this technology will not be considered further.

Permeable Barrier Walls

Description

A permeable reaction wall is installed across the flow path of a contaminant plume, allowing the water portion of the plume to passively move through the wall. These barriers allow the passage of water while prohibiting the movement of contaminants by employing such agents as zero-valent metals, chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and others.

The contaminants will either be degraded or retained in a concentrated form by the barrier material. The wall could provide permanent containment for relatively benign residues or provide a decreased volume of the more toxic contaminants for subsequent treatment.

Funnel and Gate

Modifications to the basic passive treatment walls may involve a funnel-and-gate system or an iron treatment wall. The funnel-and-gate system for in situ treatment of contaminated plumes consists of low hydraulic conductivity (e.g., 1E-6 cm/s) cutoff walls (the funnel) with a gate that contains in situ reaction zones. Ground water primarily flows through high conductivity gaps (the gates). The type of cutoff walls most likely to be used in the current practice are slurry walls or sheet piles. Innovative methods such as deep soil mixing and jet grouting are also being considered for funnel walls.

Iron Treatment Wall

An iron treatment wall consists of iron granules or other iron bearing minerals for the treatment of chlorinated contaminants such as TCE, DCE, and VC. As the iron is oxidized, a chlorine atom is removed from the compound by one or more reductive dechlorination mechanisms, using electrons supplied by the oxidation of iron. The iron granules are dissolved by the process, but the metal disappears so slowly that the remediation barriers can be expected to remain effective for many years, possibly even decades.

Barrier and post-closure monitoring tests are being conducted by the USAF, U.S. Navy, and DOE in field-scale demonstration plots and are being designed for actual contaminated sites. The range of materials available for augmenting existing barrier practice is broad. Two types of barriers have been the focus of initial efforts of this program, i.e., permeable reactive barriers and in-place bioreactors.

Passive treatment walls are generally intended for long-term operation to control migration of contaminants in ground water.

Applicability

Target contaminant groups for passive treatment walls are VOCs, SVOCs, and inorganics. The technology can be used, but may be less effective, in treating some fuel hydrocarbons.

Limitations

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

- Passive treatment walls may lose their reactive capacity, requiring replacement of the reactive medium.
- Passive treatment wall permeability may decrease due to precipitation of metal salts
- Limited to a subsurface lithology that has a continuous aquitard at a depth that is within the vertical limits of trenching equipment.
- Volume cost of treatment medium.
- Biological activity or chemical precipitation may limit the permeability of the passive treatment wall.

Costs

Complete cost data are still not available because most sites have been demonstration scale and may have been over designed for a safety margin. However, costs are decreasing as the price of reactive iron media declines and cost per unit of contaminant removed is a function of the concentrations in ground water. In general, for granular iron the cost is approximately $400 per ton. The cost range for the trenching and installation of reactive media is $750 to $1,500 per linear foot, depending on depth and width of the trench, dewatering, etc.

Site Relevance

A barrier technology pilot treatment system is currently in place for the chlorinated hydrocarbon plume in the Northeast Quadrant. The use of this technology with a sorbent media may have further application for controlling potential offsite migration of other contaminants of concern such as petroleum hydrocarbons. This technology will be considered further.

Directional Drilling

Description

Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling. Directional drilling may be used to enhance other in-situ or in-well technologies such as ground water pumping, bioventing, SVE, soil flushing, and in-well air stripping.

Hardware used for directional boring includes wireline coring rigs, hydraulic thrust systems, electric cone penetrometers, steering tracking hardware, sonic drilling, and push coring systems. Hydraulically activated thrust equipment capable of exerting more than 40 tons of thrust is used to push the directional boring heads into the earth. Directional control is obtained by proper positioning of the face of the nonsymmetric boring head. Slow rotation of the boring head will cut and compact the geologic material into the borehole wall. Thrusting a boring head that is not rotating will cause a directional change. The machinery is capable of initiating a borehole, steering down to a desired horizontal depth, continuing at that depth, and then steering back to the surface at a downrange location.

Applicability

Directional well technology is applicable to the complete range of contaminant groups with no particular target group. It is particularly useful when existing structures interfere with placement of vertical wells.

Limitations

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

- The potential exists for the wells to collapse.
- Specialized equipment is required.
- Wells are difficult to position precisely.
- Installation of horizontal wells is typically costly.
- Currently, the technology is limited to depths of less than 50 feet.

Costs

Estimated costs are about $20 to $75 per foot for hydraulic bi-directional thrust drilling. Sonic drilling can be as much as $100 per foot.

Site Relevance

Directional well technology is applicable to the complete range of contaminant groups with no particular target group. It is particularly useful when existing structures interfere with the placement of vertical wells. It may also be used to enhance other in-situ or in-well technologies such as ground water pumping, SVE, and soil flushing, and may be appropriate for areas where contamination is underlying buildings or other structures such as the main substation. This technique will be considered where bio-augmentation delivery systems may be required.

EXSITU TECHNOLOGIES

Adsorption/Absorption

Description

Adsorption mechanisms are generally categorized as either physical adsorption, chemisorption, or electrostatic adsorption. Weak molecular forces, such as Van der Waals forces, provide the driving force for physical adsorption, while a chemical reaction forms a chemical bond between the compound and the surface of the solid in chemisorption. Electrostatic adsorption involves the adsorption of ions through Coulombic forces, and is normally referred to as ion exchange, which is addressed separately in the ion exchange modules. In liquids, interactions between the solute and the solvent also play an important role in establishing the degree of adsorption.

The most common adsorbent is granulated activated carbon (GAC). Other natural and synthetic adsorbents include: activated alumina, forage sponge, lignin adsorption, sorption clays, and synthetic resins.

Activated Alumina

Activated alumina is a filter media made by treating aluminum ore so that it becomes porous and highly adsorptive. Activated alumina will remove variety of contaminants, including excessive fluoride, arsenic, and selenium. The medium requires periodic cleaning with an appropriate regenerant such as alum or acid in order to remain effective.

Forage Sponge

Forage sponge is an open-celled cellulose sponge incorporating an amine-containing chelating polymer that selectively absorbs dissolved heavy metals. The polymer is intimately bonded to the cellulose so as to minimize physical separation from the supporting matrix. The functional groups in the polymer (i.e., amine and carboxyl groups) provide selective affinity for heavy metals in both cationic and anionic states, preferentially forming complexes with transition-group heavy metals.

Lignin Adsorption/Sorptive Clay

Lignin adsorption/sorptive clays are used to treat aqueous waste streams with organic, inorganic and heavy metals contamination. The waste stream is treated due to the molecular adhesion of the contaminants to an adsorptive surface.

Synthetic Resins

Synthetic resins are much more expensive than GAC, but can be designed to achieve higher degrees of selectivity and adsorption capacity for certain compounds than activated carbon. Resins are typically regenerated using acids, bases, or organic solvents, instead of thermal methods, so they are better suited for thermally unstable compounds such as explosives, and are resistant to deactivation due to the adsorption of dissolved solids. Additionally, resins tend to be more resistant to abrasion than activated carbon, increasing their service life.

Applicability

The target contaminants groups for adsorption/absorption processes are most organic contaminants and selected inorganic contaminants from liquid and gas streams. Activated alumina can remove fluoride and heavy metals. The forager sponge is specifically used to remove heavy metals. Lignin adsorption/sorptive clays treat organic, inorganic and heavy metals contamination within aqueous waste streams. Synthetic resins are better suited for thermally unstable compounds such as explosives than GAC, due to the resins' non-thermal regeneration requirements.

Limitations

Factors that may limit the applicability and effectiveness of these processes include:

- Polar compounds are not adsorbed well by GAC.
- Costs are high if used as the primary treatment on waste streams with high contaminant concentration levels due to the disposal or regeneration of the adsorption/absorption media.
- Not applicable to sites having high levels of oily substances.
- Contaminated media often require treatment/disposal as hazardous wastes, if they can't be regenerated.

Costs

Because of the number of variables involved, establishing general costs for this technology is difficult. Estimated cost ranges per site are between $50,000 to $500,000 per site. This is typically a long term treatment technique associated with a pump and treat scenario. Costs are dependant on contaminant concentrations, groundwater extraction rates, disposition of the effluent, and duration of the operation and maintenance.

Site Relevance

Contaminated media used for adsorption of chlorinated compounds often require treatment/disposal as hazardous wastes, if they can't be regenerated. This technique is typically a long-term measure associated with a pump and treat operation. Pump and treat systems have historically had marginal success with no guarantee that the contamination will be completely removed. Costs over time are generally high, however, this technique may be applicable to obtain/maintain hydraulic control in certain AOC's and will be evaluated further.

Air Stripping

Description

Air stripping is a full-scale technology in which volatile organics are partitioned from ground water by greatly increasing the surface area of the contaminated water exposed to air. Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration. Air stripping involves the mass transfer of volatile contaminants from water to air. For ground water remediation, this process is typically conducted in a packed tower or an aeration tank. The typical packed tower air stripper includes a spray nozzle at the top of the tower to distribute contaminated water over the packing in the column, a fan to force air countercurrent to the water flow, and a sump at the bottom of the tower to collect decontaminated water. Auxiliary equipment that can be added to the basic air stripper includes an air heater to improve removal efficiencies; automated control systems with sump level switches and safety features, such as differential pressure monitors, high sump level switches, and explosion-proof components; and air emission control and treatment systems, such as activated carbon units, catalytic oxidizers, or thermal oxidizers. Packed tower air strippers are installed either as permanent installations on concrete pads or on a skid or a trailer.

Modifying packing configurations greatly increase removal efficiency. A low-profile air stripper is offered by several commercial vendors. This unit packs a number of trays in a very small chamber to maximize air-water contact while minimizing space. Because of the significant vertical and horizontal space savings, these units are increasingly being used for ground water treatment.

Air strippers can be operated continuously or in a batch mode where the air stripper is intermittently fed from a collection tank. The batch mode ensures consistent air stripper performance and greater energy efficiency than continuously operated units because mixing in the storage tanks eliminates any inconsistencies in feed water composition.

The eventual duration of cleanup using an air stripping system may be tens of years and depends on the capture of the entire plume from the ground water.

Applicability

Air stripping is used to separate VOCs from water. It is ineffective for inorganic contaminants. Henry's law constant is used to determine whether air stripping will be effective. Generally, organic compounds with constants greater than 0.01 atmospheres - m3/mol are considered amenable to stripping. Some compounds that have been successfully separated from water using air stripping include BTEX, chloroethane, vinyl chloride, TCE, DCE, and PCE.

Limitations

The following factors may limit the applicability and effectiveness of the process:

- The potential exists for inorganic (e.g., iron greater than 5 ppm, hardness greater than 800 ppm) or biological fouling of the equipment, requiring pretreatment or periodic column cleaning.
- Effective only for contaminated water with VOC or semivolatile concentrations with a dimensionless Henry's constant greater than 0.01.
- Process energy costs are high.
- Compounds with low volatility at ambient temperature may require pre-heating of the ground water.
- Off-gases may require treatment based on mass emission rate.

Cost

A major operating cost of air strippers is the electricity required for the ground water pump, the sump discharge pump, and the air blower. The power rating of the ground water pump depends on the pressure head and pressure drop across the column and should be obtained from pump curves.

Site Relevance

This technique is typically a long-term measure associated with a pump and treat operation. Pump and treat systems have historically had marginal success with no guarantee that the contamination will be completely removed. Costs over time are generally high, however, this technique may be applicable to obtain/maintain hydraulic control in certain AOCs. This technique may be relevant for certain AOCs and will be evaluated further.

Precipitation, Coagulation, Flocculation

Description

Precipitation of metals has long been the primary method of treating metal-laden industrial wastewaters. As a result of the success of metals precipitation in such applications, the technology is being considered and selected for use in remediating ground water containing heavy metals, including their radioactive isotopes. In ground water treatment applications, the metal precipitation process is often used as a pretreatment for other treatment technologies (such as chemical oxidation or air stripping) where the presence of metals would interfere with the other treatment processes.

Metals precipitation from contaminated water involves the conversion of soluble heavy metal salts to insoluble salts that will precipitate. The precipitate can then be removed from the treated water by physical methods such as clarification (settling) and/or filtration. The process usually uses pH adjustment, addition of a chemical precipitant, and flocculation. Typically, metals precipitate from the solution as hydroxides, sulfides, or carbonates. The solubilities of the specific metal contaminants and the required cleanup standards will dictate the process used. In some cases, process design will allow for the generation of sludges that can be sent to recyclers for metal recovery.

Coagulants and Flocculation

In the precipitation process, chemical precipitants, coagulants, and flocculantation are used to increase particle size through aggregation. The precipitation process can generate very fine particles that are held in suspension by electrostatic surface charges. These charges cause clouds of counter-ions to form around the particles, giving rise to repulsive forces that prevent aggregation and reduce the effectiveness of subsequent solid-liquid separation processes. Therefore, chemical coagulants are often added to overcomethe repulsive forces of the particles. The three main types of coagulants are inorganic electrolytes (such as alum, lime, ferric chloride, and ferrous sulfate), organic polymers, and synthetic polyelectrolytes with anionic or cationic functional groups. The addition of coagulants is followed by low-sheer mixing in a flocculator to promote contact between the particles, allowing particle growth through the sedimentation phenomenon called flocculant settling.

Flocculant settling refers to a rather dilute suspension of particles that coalesce, or flocculate, during the sedimentation operation. As coalescence or flocculation occurs, the particles increase in mass and settle at a faster rate. The amount of flocculation that occurs depends on the opportunity for contact, which varies with the overflow rate, the depth of the basin, the velocity gradients in the system, the concentration of particles, and the range of particles sizes. The effects of these variables can only be accomplished by sedimentation tests.

Applicability

Precipitation is used mainly to convert dissolved ionic species into solid-phase particulates that can be removed from the aqueous phase by coagulation and filtration. Remedial application of this technology usually involve removal of dissolved toxic metals and radionuclides. Depending on the process design, sludges may be amenable to metal recovery.

Limitations

Disadvantages of metals precipitation may include:

- As with any pump and treat process, if the source of contamination is not removed (as in metals absorbed to soil), treatment of the ground water may be superfluous.
- The presence of multiple metal species may lead to removal difficulties as a result of amphoteric natures of different compounds (i.e., optimization on one metal species may prevent removal of another).
- As discharge standards become more stringent, further treatment may be required.
- Metal hydroxide sludges must pass TCLP prior to land disposal.
- Soluble hexavalent chrome requires extra treatment prior to coagulaation and flocculation.
- Reagent addition must be carefully controlled to preclude unacceptable concentrations in treatment effluent.
- Efficacy of the system relies on adequate solids separation techniques (e.g., clarification, flocculation, and/or filtration).
- Process may generate toxic sludge requiring proper disposal.
- Process can be costly, depending on reagents used, required system controls, and required operator involvement in system operation.
- Dissolved salts are added to the treated water as a result of pH adjustment.
- Polymer may need to be added to the water to achieve adequate settling of solids.
- Treated water will often require pH adjustment.
- Metals held in solution by complexing agents (e.g., cyanide or EDTA) are difficult to precipitate.

Costs

The primary capital cost factor is design flow rate. Capital costs for 75- and 250-liters-per-minute (20-gpm and 65-gpm) packaged metals precipitation systems are approximately $85,000 and $115,000, respectively (excluding architectural costs, etc.).

The primary factors affecting operating costs are labor and chemical costs. Operating costs (excluding sludge disposal) are typically in a range from $0.08 to $0.18 per 1,000 liters ($0.30 to $0.70 per 1,000 gallons) of ground water containing up to 100 mg/L of metals.

For budgetary purposes, sludge disposal may be estimated to increase operating costs by approximately $0.13 per 1,000 liters ($0.50 per 1,000 gallons) of ground water treated. Actual sludge disposal costs (including fixation and transportation) have been estimated at approximately $330 per metric ton ($300 per ton) of sludge.

Costs for performing a laboratory treatability study for metals precipitation may range from $5,000 to $20,000. Depending on the degree of uncertainty or other requirements, a pilot or field demonstration may be needed. Associated costs may range from $50,000 to $250,000 (depending on scale, analytical requirements, and duration).

Site Relevance

The metal precipitation process is often used as a pre-treatment for other treatment technologies (such as chemical oxidation or air stripping) where the presence of metals would interfere with the other treatment processes. The process can be costly, depending on reagents used, required system controls, and required operator involvement in system operation. However, metals concentrations may not significantly affect the removal of the COC's at the Siberia Area. This technique may not be a necessary pre-treatment measure and most likely not cost effective. Therefore, it will not be considered further.

Ion Exchange

Description

Ion exchange removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange medium. Ion exchange materials may consist of resins made from synthetic organic materials that contain ionic functional groups to which exchangeable ions are attached. They also may be inorganic and natural polymeric materials. After the resin capacity has been exhausted, resins can be regenerated for re-use.

The duration of ion exchange technology is typically short- to medium-term depending on the factors discussed in Data Needs.

Applicability

Ion exchange can remove dissolved metals and radionuclides from aqueous solutions. Other compounds that have been treated include nitrate, ammonia nitrogen, and silicate.

Limitations

Factors that may affect the applicability and effectiveness of this process include:

- Oil and grease in the ground water may clog the exchange resin.
- Suspended solids content greater than 10 ppm may cause resin blinding.
- The pH of the influent water may affect the ion exchange resin selection.
- Oxidants in ground water may damage the ion exchange resin.
- Wastewater is generated during the regeneration step and will require additional treatment and disposal.

Costs

The cost for a typical ion exchange system ranges from $0.08 to $0.21 per 1,000 liters ($0.30 to $0.80 per 1,000 gallons) treated. Capital costs for the ion exchange units may cost $8,000 for a 10 GPM unit to $100,000 for a 100 GPM unit. This does not include costs associated with architectural, electronic, mechanical, etc. Key cost factors include:

- Pretreatment requirements.
- Discharge requirements and resin utilization.
- Regenerant used and efficiency.

Site Relevance

This is an exsitu treatment technology that typically has high O&M costs. Additionally, pre-treatment requirements are unavoidable and wastewater generated during the regeneration step will require treatment and disposal. The costs associated with this type of system may be significant and therefore, this may not be a cost-effective approach. Therefore, this technology will not be considered further.

UV/Oxidation

Description

UV oxidation is a destruction process that oxidizes organic and explosive constituents in wastewater by the addition of strong oxidizers and irradiation with UV light. Oxidation of target contaminants is caused by direct reaction with the oxidizers, UV photolysis, and through the synergistic action of UV light, in combination with ozone (O3) and/or hydrogen peroxide (H2O2). If complete mineralization is achieved, the final products of oxidation are carbon dioxide, water, and salts. The main advantage of UV oxidation is that it is a destruction process, as opposed to air stripping or carbon adsorption, for which contaminants are extracted and concentrated in a separate phase. UV oxidation processes can be configured in batch or continuous flow modes, depending on the throughput under consideration.

The UV oxidation process is generally done with low pressure lamps operating at 65 watts of electricity for ozone systems and lamps operating at 15kW to 60kW for hydrogen peroxide systems.

UV Photolysis

UV photolysis is the process by which chemical bonds of the contaminants are broken under the influence of UV light. Products of photo-degradation vary according to the matrix in which the process occurs, but the complete conversion of an organic contaminant to CO2 and H2O is not probable.

The duration of operation and maintenance of UV oxidation depends on influent water turbidity, contaminant and metal concentrations, existence of free radical scavengers, and the required maintenance intervals on UV reactors and quartz sleeves.

Applicability

Practically any organic contaminant that is reactive with the hydroxyl radical can potentially be treated. A wide variety of organic and explosive contaminants are susceptible to destruction by UV/oxidation, including petroleum hydrocarbons; chlorinated hydrocarbons used as industrial solvents and cleaners; and ordnance compounds such as TNT, RDX, and HMX. In many cases, chlorinated hydrocarbons that are resistant to biodegradation may be effectively treated by UV/oxidation. Typically, easily oxidized organic compounds, such as those with double bonds (e.g., TCE, PCE, and vinyl chloride), as well as simple aromatic compounds (e.g., toluene, benzene, xylene, and phenol), are rapidly destroyed in UV/oxidation processes.

Limitations

Limitations of UV/oxidation include:

- The aqueous stream being treated must provide for good transmission of UV light (high turbidity causes interference). This factor can be more critical for UV/H2O2 than UV/O3. (Turbidity does not affect direct chemical oxidation of the contaminant by H2O2 or O3.)
- Free radical scavengers can inhibit contaminant destruction efficiency. Excessive dosages of chemical oxidizers may act as a scavenger.
- The aqueous stream to be treated by UV/oxidation should be relatively free of heavy metal ions (less than 10 mg/L) and insoluble oil or grease to minimize the potential for fouling of the quartz sleeves.
- When UV/O3 is used on volatile organics such as TCA, the contaminants may be volatilized (e.g., "stripped") rather than destroyed. They would then have to be removed from the off-gas by activated carbon adsorption or catalytic oxidation.
- Costs may be higher than competing technologies because of energy requirements.
- Pretreatment of the aqueous stream may be required to minimize ongoing cleaning and maintenance of UV reactor and quartz sleeves.

- Handling and storage of oxidizers require special safety precautions.

Costs

Costs generally are between $0.03 to $3.00 per 1,000 liters ($0.10 to $10.00 per 1,000 gallons). Factors that influence the cost to implementing UV/oxidation include:

- Types and concentration of contaminants (as they affect oxidizer selection, oxidizer dosage, UV light intensity, and treatment time).
- Degree of contaminant destruction required.
- Desired water flow rates.
- Requirements for pretreatment and/or post-treatment.

Site Relevance

Essentially, this is an exsitu chem-ox system that uses UV radiation as part of its destruction process. Costs are typically higher than competing technologies because of energy requirements, pre-treatment of the aqueous stream, off-gas treatment, and the handling and storage of oxidizers. This method is a long term remedial measure with significant O&M costs and would not be cost effective compared to other measures that may be appropriate this site. This technology will not be considered further.

6.0 IDENTIFICATION OF CM ALTERNATIVES

The corrective measure alternatives that may be appropriate for remediation of the soil and groundwater in the Siberia Area have been identified in a matrix format presented in Tables 6-1 and 6-2. The matrixes identify individual technologies that may be used to achieve the corrective action objectives for each media in each AOC. Combinations of technologies may be appropriate and more cost effective due to multiple contaminants and physical constraints within the AOCs. Some of these combinations have been presented in Table 6-3 along with preliminary cost ranges. The costs were developed for each technology and combination of technologies using the ranges presented in Section 5. These cost ranges are presented in Table 6-3 as well as the estimated duration of the remedial actions (before no further action would be required) for each AOC.

TABLE 3-1
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF EXPOSURE ASSESSMENT SSTLs

	Soils								Groundwater		
Parameter	NYSDEC TAGM 4046 Value (mg/kg)	RFI Adjusted TAGM 4046 Value * (mg/kg)	NYSDEC Soil Cleanup Criteria for Perfection Plating (mg/kg)	On-Site Surface Soil SSTL (mg/kg)	All On-Site Soil SSTL (mg/kg)	Off-Site Surface Soil/Sediment SSTL (mg/kg)	Soil Saturation Concentration (mg/kg)	Average Site Specific Background Concentration (mg/kg)	NYS Class GA Water Quality Standard (mg/l)	Groundwater SSTL (mg/l)	Water Solubility Limit (mg/l)
Volatile Organic Compounds											
Benzene	0.06	0.48			32.39		5,547.54		0.0007		1,750.00
2-Butanone	0.3	3.2		9,982.37	7,199.94				0.005		
Carbon disulfide	2.7	2.4			456.30		4,061.68		N/A		1,190.00
Chloroform	0.3	5.6		5.03	13.94		23,520.54		0.007	0.04	7,920.00
1,2-Dichloroethene	0.3	0.8			2,620.51		3,708.48		0.005	15.78	3,500.00
Methylene chloride	0.1	11.2		64.57	771.08		163,740.08		0.005		13,000.00
Tetrachloroethene	1.4	12		2,015.78	2,620.51		2,917.14		0.005	11.38	200.00
Toluene	1.5	44		1,805.28	2,844.40		5,751.64		0.005		526.00
Trichloroethene	0.7	9.6					1,793.62		0.005		1,100.00
Vinyl chloride	0.2	4.8			0.29		4,701.42		0.002	0.002	2,760.00
Xylenes	1.2	8		> SSC	> SSC		3,113.19		0.005	> WS	161.00
Semivolatile Organic Compounds											
Acenaphthene	50 a	400		> SSC	> SSC	> SSC	1,560.77		0.02		4.24
Acenaphthylene	41	328							N/A		
Anthracene	50 a	400		> SSC	> SSC	> SSC	48.96		N/A	> WS	0.04
Benzidine	N/A	N/A		0.0002	0.01				0.005		
Benzo(a)anthracene	0.224 or MDL			3.15	46.27	0.99	1,037.76		0.000002	> WS	0.01
Benzo(b)fluoranthene	1.1	8.8		3.15	46.27	0.99	66.00		0.000002	> WS	0.002
Benzo(k)fluoranthene	1.1	8.8		31.49	> SSC	9.90	35.20		0.000002	> WS	0.001
Benzo(a)pyrene	0.061 or MDL			0.31	4.63	0.10	50.41		0.000002		0.002
Benzo(g,h,i)perylene	50 a	400							N/A		
bis(2-Ethylhexyl)phthalate	50 a	400		164.18	2,412.65	51.63	3,019.24		0.05	0.27	0.34
Butylbenzylphthalate	50 a	400		> SSC	> SSC	> SSC	12,331.24		0.05	> WS	2.69
Chrysene	0.4	3.2		> SSC	> SSC	> SSC	25.60		0.000002	> WS	0.002
Dibenz(a,h)anthracene	0.014 or MDL			0.31	4.63	0.10	657.36		N/A		0.002
Diethylphthalate	7.1	56.8		> SSC	> SSC	> SSC	24,911.16		0.05	> WS	1,080.00
Di-n-butylphthalate	8.1	64.8		> SSC	> SSC		30,465.19		0.05	> WS	11.20
Di-n-octylphthalate	50 a	400		16,417.67	9,650.61		134,080.00		N/A	> WS	0.02
Indeno(1,2,3-cd)pyrene	3.2	25.6		> SSC	> SSC	0.99	2.82		0.00002		0.00002
Fluoranthene	50 a	400		> SSC	> SSC	> SSC	1,779.86		0.05	> WS	0.21
Fluorene	50 a	400		> SSC	> SSC	> SSC	1,147.03		0.05	0.07	1.98
2-Methylnaphthalene	36.4	291.2							N/A		
Naphthalene	13	104					320.79		0.01		31.00
Phenanthrene	50 a	400							0.05		
Phenol	0.03 or MDL	0.24				37,171.15	197,551.20		0.001		82,800.00
Pyrene	50 a	400		> SSC	> SSC	> SSC	410.41		0.05	> WS	0.14

TABLE 3-1
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF EXPOSURE ASSESSMENT SSTLs

	Soils								Groundwater		
Parameter	NYSDEC TAGM 4046 Value (mg/kg)	RFI Adjusted TAGM 4046 Value * (mg/kg)	NYSDEC Soil Cleanup Criteria for Perfection Plating (mg/kg)	On-Site Surface Soil SSTL (mg/kg)	All On-Site Soil SSTL (mg/kg)	Off-Site Surface Soil/Sediment SSTL (mg/kg)	Soil Saturation Concentration (mg/kg)	Average Site Specific Background Concentration (mg/kg)	NYS Class GA Water Quality Standard (mg/l)	Groundwater SSTL (mg/l)	Water Solubility Limit (mg/l)
Pesticides/PCBs											
Aldrin	0.041			0.05	1.69		35,280.02		N/A		0.18
Aroclor 1254	1/10 b			0.20	0.88				0.0001		
Aroclor 1260	1/10 b			0.20	0.88				0.0001		
beta-BHC	0.2	1.6		0.46	14.55		106.97		N/A		0.24
delta-BHC	0.3	2.4							N/A		
4,4'-DDD	2.9			3.42	140.74		7,142.41		ND		0.09
4,4'-DDE	2.1			2.41	99.34		42,432.01		ND		0.12
4,4'-DDT	2.1			2.41	85.76		5,260.00		ND	0.01	0.03
Dieldrin	0.044			0.05	1.79		2,964.02		N/A		0.20
Endosulfan I	0.9	7.2		246.27	2,895.18		436.61		N/A		0.51
Endosulfan sulfate	1	8							N/A		
Endrin	0.1	0.8		246.27	144.76		1,884.03		ND		0.25
Endrin ketone	N/A	N/A							N/A		
Heptachlor epoxide	0.02	0.16		0.09	3.13		1,316.82		ND		0.20
Methoxychlor	c	c		> SSC	2,412.65		354.96		0.035		0.05
Inorganic Compounds											
Arsenic	10.5 d	23	23	<SSB	20.20	<SSB		10.5	0.025	0.75	
Barium	300			79,049.67	447.75			118	1	1,129.10	
Cadmium	1	39	39	1,129.28	35.22			0.23	0.01	8.07	
Chromium	20.7 d	390	390	> 1E+06	521,535.01			21	0.05	16,130.05	
Lead	186 d	500	500	4.00E+02 e		4.00E+02 e		186	0.025		
Mercury	0.54 d			> 1E+06	271.71			0.54	0.002		
Selenium	3.1 d			5,646.41	2,607.68			3.1	0.01	80.65	
Silver	ND d			5,646.41	2,607.68			ND	0.05		

Notes:
N/A = None Available
ND = Not Detected
MDL = Method Detection Limit
* = Adjusted TAGM values from the *RCRA Facility Investigation Report, Siberia Area, Watervliet Arsenal, Watervliet, NY*. Malcolm Pirnie, Inc., December 1997.
a = As per TAGM#4046, individual semi-volatile compounds <50 mg/kg.
b = Policy Based: For surface soil (1 mg/kg) and subsurface soil (10 mg/kg).
c = As per TAGM 4046, total pesticides < 10 mg/kg.
d = Site Background Value
e = A soil screening level of 400 mg/kg in soil at residential properties has been set (USEPA, 1998, 1994).
> SSC = SSTL is greater than the soil saturation concentration.
< SSB = SSTL is less than the site specific background concentration.
> WS = SSTL is greater than the water solubility limit.

TABLE 3-2
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
PROPOSED SOIL ACTION LEVELS

Parameter	Groundwater Quality Protection Values for Backfill* (mg/kg)	Groundwater Quality Protection Values for Native Soil* (mg/kg)	NYSDEC Soil Cleanup Criteria for Perfection Plating (mg/kg)	On-Site Surface Soil SSTL (mg/kg)	All On-Site Soil SSTL (mg/kg)	Off-Site Surface Soil/Sediment SSTL (mg/kg)	90 % of Soil Saturation Concentration (mg/kg)	Proposed Action Level for On-Site Surface Soil (mg/kg) Backfill/Native	Proposed Action Level for On-Site Subsurface Soil (mg/kg) Backfill/Native	Proposed Action Level for Off-Site Surface Soil (mg/kg)
Volatile Organic Compounds										
Benzene					32.39		4,992.79		32.39	
2-Butanone				9,982.37	7,199.94			9,982.37	7,199.94	
1,2-Dichloroethene	74.48	9.31			2,620.51		3,337.63	74.48 / 9.31	74.48 / 9.31	
Tetrachloroethene	252.17	31.52		2,015.78	2,620.51		2,625.43	252.17 / 31.52	252.17 / 31.52	
Toluene				1,805.28	2,844.40		5,176.48	1,805.28	2,844.40	
Vinyl chloride	0.01	0.0011			0.29		4,231.27	0.0088 / 0.0011	0.0088 / 0.0011	
Xylenes	3091.20	386.40		> SSC	> SSC		2,801.87	2,801.9 / 386.4	2,801.9 / 386.4	
Semivolatile Organic Compounds										
Acenaphthene				> SSC	> SSC	> SSC	1,404.69	1,404.69	1,404.69	1,404.69
Anthracene	48.61	6.08		> SSC	> SSC	> SSC	44.06	44.06 / 6.076	44.06 / 6.076	44.06
Benzo(a)anthracene	1037.76	129.72		3.15	46.27	0.99	933.98	3.15	46.27	0.99
Benzo(b)fluoranthene	66.00	8.25		3.15	46.27	0.99	59.40	3.15	46.27 /8.25	0.99
Benzo(k)fluoranthene	35.20	4.40		31.49	> SSC	9.90	31.68	31.49 / 4.4	35.20 / 4.4	9.9 / 4.4
Benzo(a)pyrene	453.20	56.65		0.315	4.627	0.10	45.37	0.315	4.627	0.1/ND
Chrysene	25.60	3.20		> SSC	> SSC	> SSC	23.04	23.04 / 3.20	23.04 / 3.20	23.04 / 3.20
Dibenz(a,h)anthracene				0.315	4.63	0.10	591.62	0.315	4.63	0.1/ND
Indeno(1,2,3-cd)pyrene				> SSC	> SSC	0.99	2.53	2.53	2.53	0.99
Fluoranthene	626.24	78.28		> SSC	> SSC	> SSC	1,601.88	626.2 4/ 78.28	626.2 4/ 78.28	626.2 4/ 78.28
Pyrene	143.59	17.95		> SSC	> SSC	> SSC	369.37	143.59 / 17.95	143.59 / 17.95	143.59 / 17.95
Inorganic Compounds										
Arsenic			23	<SSB	20.20	<SSB		23	23	10.50
Chromium			390	> 1E+06	521,535			521,535	521,535	
Lead			500	400 b		400 b		500	500	400 b

Notes:

* = Groundwater quality protection values emperically derived using the water/soil partition model assuming 8% TOC for backfill and 1% for native soil and groundwater SSTLs (where available) for Cw Value.

b = A soil screening level of 400 mg/kg in soil at residential properties has been set (USEPA, 1998, 1994).

Nuisance odor criteria is implied for all action levels for soils.

> SSC = SSTL is greater than the soil saturation concentration.

< SSB = SSTL is less than the site specific background concentration.

N/D = Not detected

TABLE 3-3
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
PROPOSED GROUNDWATER ACTION LEVELS

	Groundwater						
Parameter	Federal MCL (mg/l)	NYS MCL (mg/l)	NYS Class GA Water Quality Standard (mg/l)	Groundwater SSTL (mg/l)	90% of Water Solubility Limit (mg/l)	Proposed Action Level for On-Site Groundwater (mg/l)	Proposed Action Level for Groundwater at Site Boundaries (mg/l)
Volatile Organic Compounds							
1,2-Dichloroethene	0.07	0.005	0.005	15.78	3,150.00	15.78	0.0050
Tetrachloroethene	0.005	0.005	0.005	11.38	180.00	11.38	0.0050
Trichloroethene	0.005	0.005	0.005		990.00		0.0050
Vinyl chloride	0.002	0.002	0.002	0.002	2,484.00	0.002	0.0020
Xylenes	10	0.005	0.005	> WS	144.90	144.90	0.0050
Semivolatile Organic Compounds							
Anthracene	-	0.05	N/A	> WS	0.039	0.0391	0.0500
Benzo(a)anthracene	0.0001	0.05	0.000002	> WS	0.008	0.0085	0.000002
Benzo(b)fluoranthene	0.0002	0.05		> WS	0.001	0.0014	0.000200
Benzo(k)fluoranthene	0.0002	0.05		> WS	0.001	0.0007	0.000200
Benzo(a) pyrene	0.0002		0.000002/ND	0.00103*	0.002	0.0010	0.000002/ND
Chrysene	-	0.05	0.000002	> WS	0.001	0.0014	0.000002
Fluoranthene	-	0.05	0.05	> WS	0.185	0.1854	0.0500
Fluorene	-	0.05	0.05	0.07	1.782	0.0700	0.0500
2-Methylnaphthalene	-	0.05	N/A				0.0500
Naphthalene	-	0.05	0.01		27.90		0.0100
Phenanthrene	-	0.05	0.05				0.0500
Pyrene	-	0.05	0.05	> WS	0.122	0.1215	0.0500
Inorganic Compounds							
Arsenic	0.05	0.05	0.025	0.75		0.75	0.0250
Chromium	0.05	0.1	0.05	16,130.05		16,130.05	0.0500
Lead	0.015 a		0.025				0.015 a

Notes:
N/A = None Available
> WS = SSTL is greater than the water solubility limit.
a = Treatment Technique Action Level
Federal MCL = Maximum Contaminant Levels as published in USEPA Drinking Water Regulations and Health Advisories; October 1996
NYS MCL = Maximum Contaminant Levels as published in New York State Title 10, Chapter 1, Part 5, Subpart 5-1; April 30, 1997
* = Groundwater SSTL not developed in Exposure Assessment, however, developed using same methodology as other carcinogenic PAH SSTLs in Exposure Assessment.
ND = Not detected.

TABLE 4-1
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF AREAS OF CONCERN

AOC	Contaminant Type	Estimated Volume (yd^3)	Description	Historic Depth to Water (ft bgs)	AOC Estimated Vertical Extent (ft bgs)	
					AOC Surface	AOC Total Depth
NORTHEAST QUADRANT						
NE-SOIL-01	PAH/TPH	6,000	Surface Soil	2.5 - 3.5	0	1
NE-SOIL-02	PAH/TPH & METALS	1,200	Surface Soil	2.5 - 3.5	0	1
NE-SOIL-03	PAH/TPH & Metals[1]	900	Subsurface Soil	2.5 - 3.5	1	4
NE-SOIL-04	METALS	1,100	Subsurface Soil	2.5 - 3.5	1	2
NE-GW-01	VOCs	-	Overburden Groundwater	<1 - >5	1	12
NE-GW-02	VOCs	-	Bedrock Groundwater	7.5 - 8.5	10	95
NE-GW-03	PAH/TPH	1,200[2]	Overburden Groundwater	2.5 - 3.5	4	7
NORTHWEST QUADRANT						
NW-SOIL-01	PAH/TPH & METALS	135	Surface Soil	2.0 - 3.5	0	1
NW-SOIL-02	PAH/TPH	2,700	Surface Soil	2.0 - 3.5	0	1
NW-SOIL-03	PAH/TPH	2,100	Subsurface Soil	2.0 - 3.5	1	4
NW-SOIL-04	METALS	135	Subsurface Soil	2.0 - 3.5	1	2
NW-GW-01	PAH/TPH	11,200	Overburden Groundwater	2.0 - 3.5	4	20
SOUTHEAST QUADRANT						
SE-SOIL-01	PAH/TPH	3,100	Surface Soil	1.4 - 3.5	0	1
SE-SOIL-02	PAH/TPH	5,400	Subsurface Soil	1.4 - 3.5	1	4
SE-GW-01	PAH/TPH	3,600[2]	Overburden Groundwater	1.4 - 3.5	4	6
SOUTHWEST QUADRANT						
SW-SOIL-01	PAH/TPH & METALS	1,400	Subsurface Soil	2.5 - 3.5	0.5	4
SW-SOIL-02	PAH/TPH	12,000	Subsurface Soil	2.5 - 3.5	0.5	4
SW-GW-01	PAH/TPH	17,500[2]	Overburden Groundwater	2.5 - 3.5	3	8
OFF-SITE						
Offsite-SOIL-01	Metals	750	Surface Soil	-	0	1

[1] = Metals contamination limited to a portion of the upper 1 foot of the AOC.

2 = It may be feasible to treat contamination in the saturated zone concurrently with unsaturated soil using the same technologies.

TABLE 5-1
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF TECHNOLOGIES FOR SOIL MEDIA

Technology	Effectiveness	Implementability	Cost	Duration	Retained for further Evaluation?
INSITU TECHNOLOGIES					
Natural Attenuation	Effective for VOC and SVOC contamination; may not be appropriate for inorganics.	Easily implemented; preliminary bench-scale treatability study results indicate that indigenous microorganisms will aerobically degrade organic contaminants.	Low	>10 yrs	**Yes**
Enhanced Bioremediation	Effective for VOC and SVOC contamination; may not be appropriate for inorganics.	Easily implemented; Bioenhancement (i.e., thermal, nutrients, oxygen, mixing, etc.) will substantially increase the degradation rate. Innoculum may aid in rapidly meeting clean up objectives.	Low	2 to 5 yrs	**Yes**
Chemical Oxidation	Oil and grease may be prohibitive to process. Large amounts of oxidizing agent required for high contaminant concentrations.	Moderate to difficult to deliver to contaminated zones due to low permeability of soil. Delivery may be improved if coupled with ER.	Moderate to High	<2 yrs	**No**
Soil Flushing	Has been used effectively for inorganics; may be effective for mobilizing SVOCs.	Delivery and extraction systems must be installed in order to effectively implement. Residuals must be extracted/treated.	Low to Moderate	< 2 yrs to 5 yrs	**No**
Stabilization/Solidification (chemical/physical)	Effectively reduces leachability and mobility of inorganics.	Utilizes conventional materials and has been demonstrated as effective. May require long-term monitoring.	Low to Moderate	<2 yrs to > 10 yrs	**Yes**
In-Situ Vitrification	Effectively reduces leachability and mobility of inorganics.	Difficult due to high water table and existing structures.	High	<2 yrs	**No**
Electrokinetic Separation	Effectiveness not extensively documented in the United States.	Easily implemented; electrode spacing and contaminant travel times determined in pilot test.	Low	< 2 yrs to 5 yrs	**Yes**
Soil Vapor Extraction	Effective for VOCs; less effective for SVOC contamination; not appropriate for inorganics.	Difficult due to high water table/limited vadose zone.	Low	2 to 5 yrs	**No**

TABLE 5-1
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF TECHNOLOGIES FOR SOIL MEDIA

Technology	Effectiveness	Implementability	Cost	Duration	Retained for further Evaluation?
Thermally Enhanced SVE	Effective for VOC and SVOC contamination; not appropriate for inorganics.	Moderate due to high water table, however horizontal extraction trenches and cap may be used. Thermal enhancement may increase soil permeability and may be used to target organics in the saturated and vadose zones. Extraction system may have to remain dormant during high water table conditions.	Low to Moderate	< 2 to 5 yrs	**Yes**
Capping	Effective containment technology.	Easily implemented	Low	>10 yrs	**Yes**
EXSITU TECHNOLOGIES					
Excavation and Off-Site Disposal	Effective for organic and inorganic contamination	Easily implemented.	Moderate to High	< 2 yrs	**Yes**
Bio-Pile	Effective for VOC and SVOC contamination; may not be appropriate for inorganics.	Easily implemented; Bioenhancement (i.e., thermal, nutrients, oxygen, mixing, etc.) will substantially increase the degradation rate. Innoculum may aid in rapidly meeting clean up objectives.	Moderate	2 to 5 yrs	**Yes**
Incineration	Effective for VOC and SVOC contamination; not be appropriate for inorganics. Soil Moisture may significantly increase costs.	Easily implemented. Air permitting and community perception may be prohibitive.	Moderate to High	< 2 yrs	**No**
Thermal Desorption	Effective for VOC and SVOC contamination; not be appropriate for inorganics. Soil Moisture may significantly increase costs.	Easily implemented. Air permitting and community perception may be prohibitive.	Low to High	< 2 yrs	**Yes**

TABLE 5-2
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF TECHNOLOGIES FOR GROUNDWATER MEDIA

Technology	Effectiveness	Implementability	Cost	Duration	Retained for further Evaluation?
INSITU TECHNOLOGIES					
Natural Attenuation	Effective for VOC and SVOC contamination; may not be appropriate for inorganics.	Easily implemented; bench-scale treatability study is necessary to determine whether indigenous microorganisms will aerobically and/or anaerobically degrade organic contaminants in saturated zone.	Low	>10 yrs	**Yes**
Enhanced Bioremediation	Effective for VOC and SVOC contamination; may not be appropriate for inorganics.	Easily implemented; Bioenhancement (i.e., thermal, nutrients, oxygen, mixing, etc.) will substantially increase the degradation rate. Innoculum may aid in rapidly meeting clean up objectives.	Low	2 to 5 yrs	**Yes**
Chemical Oxidation	Oil and grease may be prohibitive to process. Large amounts of oxidizing agent required for high contaminant concentrations.	Moderate to difficult to deliver to contaminated zones due to low permeability of soil.	Moderate to High	<2 yrs	**Yes**
Electrokinetic Separation	Effectiveness not extensively documented in the United States.	Easily implemented; electrode spacing and contaminant travel times determined in pilot test.	Low	< 2 yrs to 5 yrs	**Yes**
Air Sparging	Effective for VOCs; less effective for SVOC contamination; not appropriate for inorganics.	Difficult due to low permeability and overall heterogeneity of soil.	Low to Moderate	2 to 5 yrs	**No**
In-Well Stripping	Effective for VOC contamination, less effective for SVOCs; not appropriate for inorganics.	Difficult due to shallow water table and low permeability soils.	Moderate to High	>10 yrs	**No**
Dual Phase Extraction	Effective for VOC contamination, less effective for SVOCs; not appropriate for inorganics.	Difficult due to low permeability and overall heterogeneity of soil.	Low to Moderate	2 to 5 yrs	**No**

TABLE 5-2
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF TECHNOLOGIES FOR GROUNDWATER MEDIA

Technology	Effectiveness	Implementability	Cost	Duration	Retained for further Evaluation?
Vertical Barriers	Effective containment technology. Must be used in conjunction with cap.	Easily implemented	Low	<2 yrs	**Yes**
Permeable Barrier Technologies	Documentation of full-scale, long term results not available.	Easily implemented. If sorbents, microbes, or chelators are used, may need to regenerate as the reactive medium becomes spent.	Low to Moderate	2 to 5 yrs	**Yes**
Recovery Wells/Trenches Directional Drilling	Effective extraction or delivery method.	System relatively easy to implement.	Moderate to High	2 to 5 yrs	**Yes**
EXSITU TECHNOLOGIES					
Recovery Wells/Trenches	Effective method for extracting groundwater or for delivery associated with augmentation.	System relatively easy to implement.	Moderate to High	> 10 yrs	**Yes**
Adsorption/Absorption	Effective treatment for organics and potentially inorganics in extracted groundwater.	Long term system relatively easy to implement given appropriate extraction system installation.	Moderate to High	> 10 yrs	**Yes**
Precipitation/Coagulation/ Flocculation	Effective treatment for inorganics in extracted groundwater.	Long term system relatively easy to implement given appropriate extraction system installation.	Moderate to High	> 10 yrs	**No**
Ion Exchange	Effective treatment for inorganics in extracted groundwater.	Long term system relatively easy to implement given appropriate extraction system installation.	Moderate to High	> 10 yrs	**No**
Air Stripping	Effective treatment for volatile organics in extracted groundwater, less effective for SVOCs.	Long term system relatively easy to implement given appropriate extraction system installation.	High	> 10 yrs	**Yes**
UV/Oxidation	Effective treatment for volatile organics in extracted groundwater, less effective for SVOCs.	Long term system relatively easy to implement given appropriate extraction system installation.	High	> 10 yrs	**No**

TABLE 6-1
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
CORRECTIVE MEASURES TECHNOLOGY MATRIX - SOIL

APPLICABLE TECHNOLOGIES	NE-SOIL-01	NE-SOIL-02	NE-SOIL-03	NE-SOIL-04	NW-SOIL-01	NW-SOIL-02	NW-SOIL-03	NW-SOIL-04	SE-SOIL-01	SE-SOIL-02	SW-SOIL-01	SW-SOIL-02
IN-SITU TECHNOLOGIES												
Natural Attenuation	X	X	X		X	X	X		X	X	X	X
Enhanced Bioremediation	X	X	X		X	X	X		X	X	X	X
Stabilization/Solidification		X		X	X			X			X	
Electrokinetic Separation			X				X			X	X	X
Thermally Enhanced SVE			X				X			X	X	X
Vertical Barriers											X	X
Capping	X	X			X	X			X	X	X	X
EX-SITU TECHNOLOGIES												
Excavation and Off-Site Disposal	X	X	X	X	X	X	X	X	X	X	X	X
Bio Cells/Bio Piles	X	X	X		X	X	X		X	X	X	X
Thermal Desorption	X	X	X		X	X	X		X	X	X	X

TABLE 6-2
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
CORRECTIVE MEASURES TECHNOLOGY MATRIX - GROUNDWATER

APPLICABLE TECHNOLOGIES	NE-GW-01	NE-GW-02	NE-GW-03	NW-GW-01	SE-GW-01	SW-GW-01
IN-SITU TECHNOLOGIES						
Natural Attenuation		X	X	X	X	X
Enhanced Bioremediation		X	X	X	X	X
Chemical Oxidation		X	X	X	X	X
Electrokinetic Separation			X	X	X	X
Permeable Barrier Technologies	X		X		X	X
EX-SITU TECHNOLOGIES						
Adsorption/Absorption		X				
Air Stripping		X				

TABLE 6-3
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF CORRECTIVE MEASURES ALTERNATIVES

AOC	Description	Applicable Technology(s)	Preliminary Cost Range (in millions of dollars)	Estimated Duration (to AOC closure)
NORTHEAST QUADRANT				
NE-SOIL-01	Surface Soil; PAH/TPH contamination.	Natural Attenuation	0.06 to 0.25[1]	>10 years
		In-Situ Enhanced Bioremediation	0.12 to 0.48	2 to 5 years
		In-Situ Enhanced Bioremediation + Natural Attenuation	0.18 to 0.73[1]	>10 years
		Bio Cells/Bio Piles	0.15 to 1.20	2 to 5 years
		Excavation and Off-Site Disposal	1.17 to 1.89	<2 years
		Cap + Natural Attenuation	0.33 to 0.79	>10 years
		Cap	0.27 to 0.54	<2 years
		On-Site Thermal Desorption	0.45 to 2.70	<2 years
NE-SOIL-02	Surface Soil; PAH/TPH and metals contamination.	Natural Attenuation	0.06 to 0.25[1]	>10 years
		In-Situ Enhanced Bioremediation + Stabilize/Solidify	0.06 to 0.40	2 to 5 years
		Bio Cells/Bio Piles + Stabilize/Solidify	0.07 to 0.54	2 to 5 years
		Excavation and Off-Site Disposal	0.23 to 0.38	<2 years
		Stabilize/Solidify + Cap + Natural Attenuation	0.15 to 0.66[1]	>10 years
		Stabilize/Solidify + Cap	0.09 to 0.41	<2 years
		On-Site Thermal Desorption + Stabilize/Solidify	0.13 to 0.84	<2 years
NE-SOIL-03	Subsurface Soil (vadose/saturated); PAH/TPH contamination; metals contamination in limited portion of vadose zone to be treated with NE-Soil-02 soils.	Natural Attenuation	0.06 to 0.25[1]	>10 years
		In-Situ Enhanced Bioremediation	0.02 to 0.07	2 to 5 years
		In-Situ Enhanced Bioremediation + Natural Attenuation	0.08 to 0.32[1]	>10 years
		Bio Cells/Bio Piles	0.02 to 0.18	2 to 5 years
		Excavation and Off-Site Disposal (vadose zone)	0.18 to 0.28	<2 years
		Excavation and Off-Site Disposal (vadose + saturated zone)	0.41 to 0.66	
		On-Site Thermal Desorption	0.07 to 0.41	<2 years
		Thermally Enhanced SVE	0.03 to 0.14	2 to 5 years
NE-SOIL-04	Subsurface Soil; Metals contamination.	Stabilize/Solidify	0.03 to 0.28	<2 years
		Excavation and Off-Site Disposal	0.21 to 0.35	<2 years

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[1] = Cost range includes 10 years of monitoring.

TABLE 6-3
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF CORRECTIVE MEASURES ALTERNATIVES

AOC	Description	Applicable Technology(s)	Preliminary Cost Range (in millions of dollars)	Estimated Duration (to AOC closure)
NE-GW-01	Overburden Groundwater (VOC Plume)	Permeable Barrier Technology (zero valent iron wall)	(installation complete)	>10 years
NE-GW-02	Bedrock Groundwater (in vicinity of MW-41); VOC contamination	Natural Attenuation	0.06 to 0.25 [1]	>10 years
		In-Situ Enhanced Bioremediation	0.10 to 0.25	2 to 5 years
		Chemical Oxidation	0.08 to 0.25	<2 years
		Pump and Treat using GAC (i.e., Adsorption/Absorption)	0.40 to 0.68 [1]	>10 years
NE-GW-03	Overburden Groundwater (w/in areal extent of NE-Soil-03); PAH/TPH contamination.	Natural Attenuation	0.06 to 0.25 [1]	>10 years
		In-Situ Enhanced Bioremediation	0.02 to 0.96	2 to 5 years
		Permeable Barrier Technology (in series w/ NE-GW-01 zero valent iron wall)	0.40 to 0.68	>10 years
		Thermally Enhanced SVE (in conjunction w/ NE-SOIL-03 saturated soil)	0.03 to 0.14	<2 years
NORTHWEST QUADRANT				
NW-SOIL-01	Surface Soil; PAH/TPH and metals contamination.	Natural Attenuation	0.06 to 0.25 [1]	>10 years
		In-Situ Enhanced Bioremediation + Stabilize/Solidify	0.06 to 0.26	2 to 5 years
		Bio Cells/Bio Piles + Stabilize/Solidify	0.01 to 0.06	2 to 5 years
		Excavation and Off-Site Disposal	0.03 to 0.04	<2 years
		Stabilize/Solidify + Cap	0.01 to 0.05	<2 years
		Stabilize/Solidify + Cap + Natural Attenuation	0.07 to 0.30 [1]	>10 years
		On-Site Thermal Desorption + Stabilize/Solidify	0.02 to 0.10	<2 years
NW-SOIL-02	Surface Soil; PAH/TPH contamination.	Natural Attenuation	0.06 to 0.25 [1]	>10 years
		In-Situ Enhanced Bioremediation	0.05 to 0.22	2 to 5 years
		In-Situ Enhanced Bioremediation + Natural Attenuation	0.11 to 0.45 [1]	>10 years
		Bio Cells/Bio Piles	0.07 to 0.54	2 to 5 years
		Excavation and Off-Site Disposal	0.53 to 0.85	<2 years
		Cap	0.12 to 0.24	<2 years
		Cap + Natural Attenuation	0.20 to 0.49 [1]	>10 years
		On-Site Thermal Desorption	0.20 to 1.22	<2 years

---

[1] = Cost range includes 10 years of monitoring.

TABLE 6-3
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF CORRECTIVE MEASURES ALTERNATIVES

AOC	Description	Applicable Technology(s)	Preliminary Cost Range (in millions of dollars)	Estimated Duration (to AOC closure)
NW-SOIL-03	Subsurface Soil (vadose/saturated); PAH/TPH contamination.	Natural Attenuation	0.06 to 0.25 [1]	>10 years
		In-Situ Enhanced Bioremediation	0.05 to 0.22	2 to 5 years
		In-Situ Enhanced Bioremediation + Natural Attenuation	0.11 to 0.47 [1]	>10 years
		Bio Cells/Bio Piles	0.07 to 0.54	2 to 5 years
		Excavation and Off-Site Disposal	0.53 to 0.85	<2 years
		On-Site Thermal Desorption	0.20 to 1.22	<2 years
		Thermally Enhanced SVE	0.10 to 0.41	2 to 5 years
NW-GW-01	Overburden Groundwater (w/in areal extent of NW-Soil-03); PAH/TPH contamination.	Natural Attenuation	0.06 to 0.25 [1]	>10 years
		In-Situ Enhanced Bioremediation (w/ NW-Soil-03 saturated soil)	0.22 to 0.90	2 to 5 years
		Chemical Oxidation (in conjunction w/ NW-SOIL-03 saturated soil)	1.68 to 5.60	<2 years
		Chemical Oxidation + Electrokinetics (in conjunction w/ NW-SOIL-03 saturated soil)	1.96 to 6.44	<2 years
NW-SOIL-04	Subsurface Soil; Metals contamination.	Stabilize/Solidify	0.01 to 0.03	<2 years
		Excavation and Off-Site Disposal	0.03 to 0.04	<2 years
SOUTHEAST QUADRANT				
SE-SOIL-01	Surface Soil; PAH/TPH contamination.	Natural Attenuation	0.06 to 0.25 [1]	>10 years
		In-Situ Enhanced Bioremediation	0.62 to 0.25	2 to 5 years
		In-Situ Enhanced Bioremediation + Natural Attenuation	0.12 to 0.50 [1]	>10 years
		Bio Cells/Bio Piles	0.08 to 0.62	2 to 5 years
		Excavation and Off-Site Disposal	0.61 to 0.98	<2 years
		Cap	0.14 to 0.28	<2 years
		Cap + Natural Attenuation	0.20 to 0.53 [1]	>10 years
		On-Site Thermal Desorption	0.23 to 1.40	<2 years

---

[1] = Cost range includes 10 years of monitoring.

TABLE 6-3
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF CORRECTIVE MEASURES ALTERNATIVES

AOC	Description	Applicable Technology(s)	Preliminary Cost Range (in millions of dollars)	Estimated Duration (to AOC closure)
SE-SOIL-02	Subsurface Soil (vadose/saturated); PAH/TPH contamination.	Natural Attenuation	0.06 to 0.25[1]	>10 years
		In-Situ Enhanced Bioremediation	0.11 to 0.43	2 to 5 years
		In-Situ Enhanced Bioremediation + Natural Attenuation	0.17 to 0.68[1]	>10 years
		Bio Cells/Bio Piles	0.14 to 1.08	2 to 5 years
		Excavation and Off-Site Disposal (vadose zone)	1.05 to 1.70	<2 years
		Excavation and Off-Site Disposal (vadose + saturated zones)	1.76 to 2.83	<2 years
		On-Site Thermal Desorption	0.41 to 2.43	<2 years
		Thermally Enhanced SVE	0.19 to 0.81	2 to 5 years
SE-GW-01	Overburden Groundwater (w/in areal extent of SE-Soil-03); PAH/TPH contamination.	Natural Attenuation	0.06 to 0.25[1]	>10 years
		In-Situ Enhanced Bioremediation (w/ SE-Soil-03 saturated soil)	0.07 to 0.29	2 to 5 years
		Permeable Barrier Technology	0.40 to 0.68	>10 years
		Thermally Enhanced SVE (in conjunction w/ SE-SOIL-03 saturated soil)	0.09 to 0.36	2 to 5 years
		Chemical Oxidation (in conjunction w/ SE-SOIL-03 saturated soil)	0.54 to 1.98	<2 years
		Chemical Oxidation + Electrokinetics (in conjunction w/ SE-SOIL-03 saturated soil)	0.60 to 2.39	<2 years
SOUTHWEST QUADRANT				
SW-SOIL-01	Subsurface Soil (vadose/saturated); PAH/TPH and metals contamination;	Natural Attenuation	0.06 to 0.25[1]	>10 years
		In-Situ Enhanced Bioremediation + Stabilize/Solidify	0.07 to 0.46	2 to 5 years
		In-Situ Enhanced Bioremediation + Stab/Solidify + Natural Attenuation	0.13 to 0.71[1]	>10 years
		Bio Cells/Bio Piles (excluding area under Substation) + Stabilize/Solidify + Natural Attenuation (beneath Substation)	0.14 to 0.88[1]	2 to 5 years
		Excavation and Off-Site Disposal (vadose zone around substation)	0.27 to 0.44	
		Excavation and Off-Site Disposal (vadose + saturated zones around substation)	0.47 to 0.76	<2 years
		Electrokinetics under substation + Excavation and Off-Site Disposal (around substation vadose zone)	0.48 to 0.79	2 to 5 years

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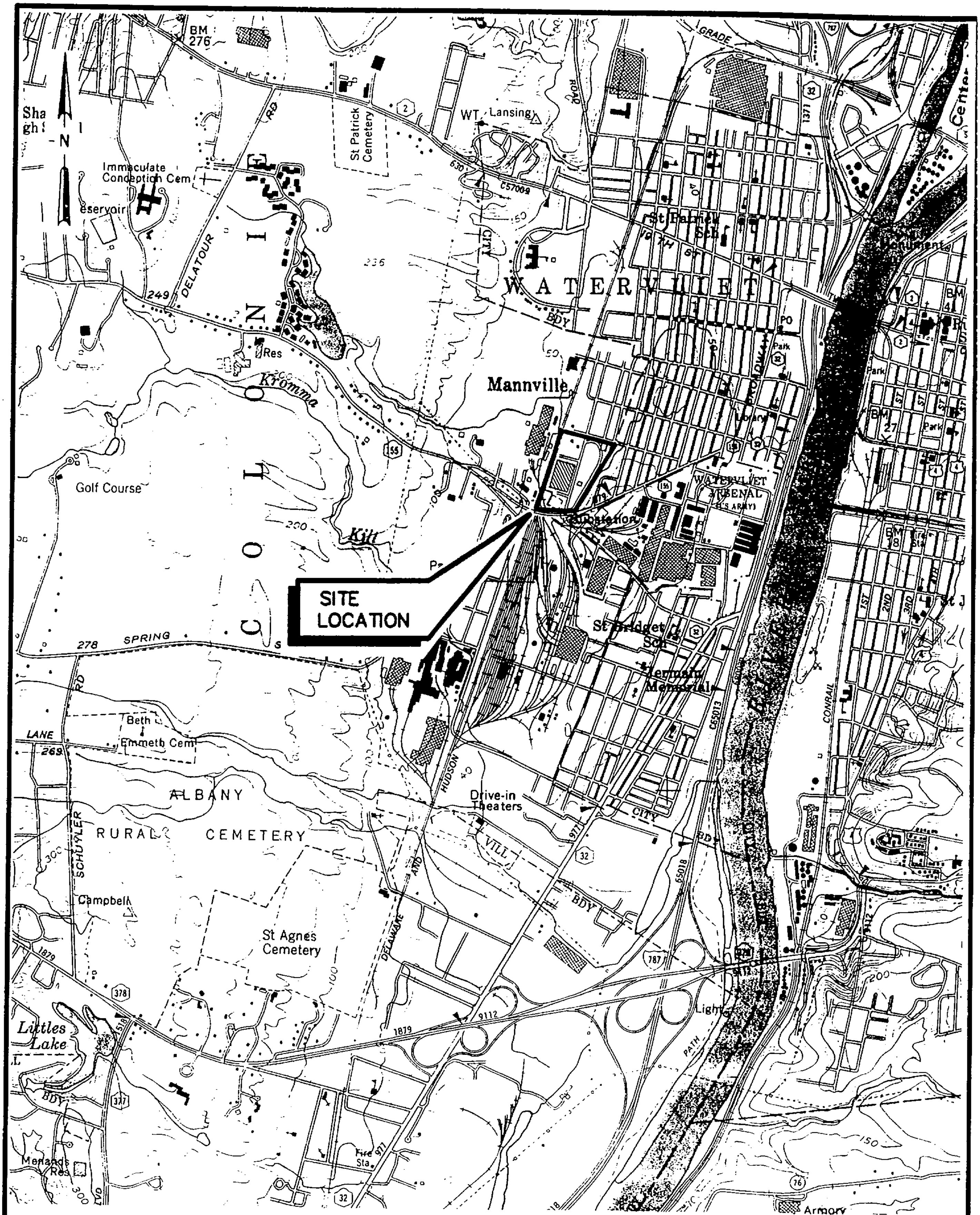
[1] = Cost range includes 10 years of monitoring.

TABLE 6-3
CORRECTIVE MEASURES PRELIMINARY SCREENING
WATERVLIET ARSENAL
SIBERIA AREA
SUMMARY OF CORRECTIVE MEASURES ALTERNATIVES

AOC	Description	Applicable Technology(s)	Preliminary Cost Range (in millions of dollars)	Estimated Duration (to AOC closure)
SW-SOIL-02	Subsurface Soil (vadose/saturated); PAH/TPH contamination;	Natural Attenuation	0.06 to 0.25[1]	>10 years
		In-Situ Enhanced Bioremediation	0.27 to 1.06	2 to 5 years
		In-Situ Enhanced Bioremediation + Natural Attenuation	0.33 to 1.31[1]	>10 years
		Bio Cells/Bio Piles (excluding Substation) + Natural Attenuation (beneath Substation)	0.39 to 2.90[1]	>10 years
		Excavation (vadose zone around Substration) and Off-Site Disposal + Natural Attenuation (beneath Substation)	2.08 to 3.51[1]	>10 years
		Electrokinetics (beneath Substation) + Excavation (around Substration) and Off-Site Disposal	2.09 to 3.48	2 to 5 years
		Cap	0.06 to 0.28	>10 years
		Cap + Natural Attenuation	0.12 to 0.60	>10 years
		On-Site Thermal Desorption	0.78 to 4.66	<2 years
		Thermally Enhanced SVE	0.46 to 1.99	2 to 5 years
SW-GW-01	Overburden Groundwater (w/in areal extent of SW-Soil-01/SW-Soil-02); PAH/TPH contamination.	Natural Attenuation	0.06 to 0.25[1]	>10 years
		In-Situ Enhanced Bioremediation (in conjunction w/ SW-Soil-01/02 saturated soil)	0.38 to 1.51	2 to 5 years
		Permeable Barrier Technology	0.40 to 0.68	>10 years
		Thermally Enhanced SVE (in conjunction w/ SW-SOIL-01/02 saturated soil)	0.66 to 2.84	2 to 5 years
		Chemical Oxidation (in conjunction w/ SW-SOIL-01/02 saturated soil)	2.80 to 9.40	<2 years
		Chemical Oxidation + Electrokinetics (in conjunction w/ SW-SOIL-01/02 saturated soil)	3.30 to 10.90	<2 years
OFF-SITE SURFACE SOIL/SEDIMENT				
Offsite-Soil-01	Surface Soil and Sediment; Metals contamination	Excavation and Stage On-Site Treatment	0.03 to 0.06	<2 years
		Excavation and Off-Site Disposal	0.15 to 0.35	<2 years

[1] = Cost range includes 10 years of monitoring.



SOURCE: TROY SOUTH 7.5 MIN. QUAD
1983 EDITION

SCALE: 1"=2000'

US Army Corps
of Engineers

SIBERIA AREA

SITE LOCATION MAP

WATERVLIET ARSENAL

USACE CONTRACT NO. DACA31-94-D-0017

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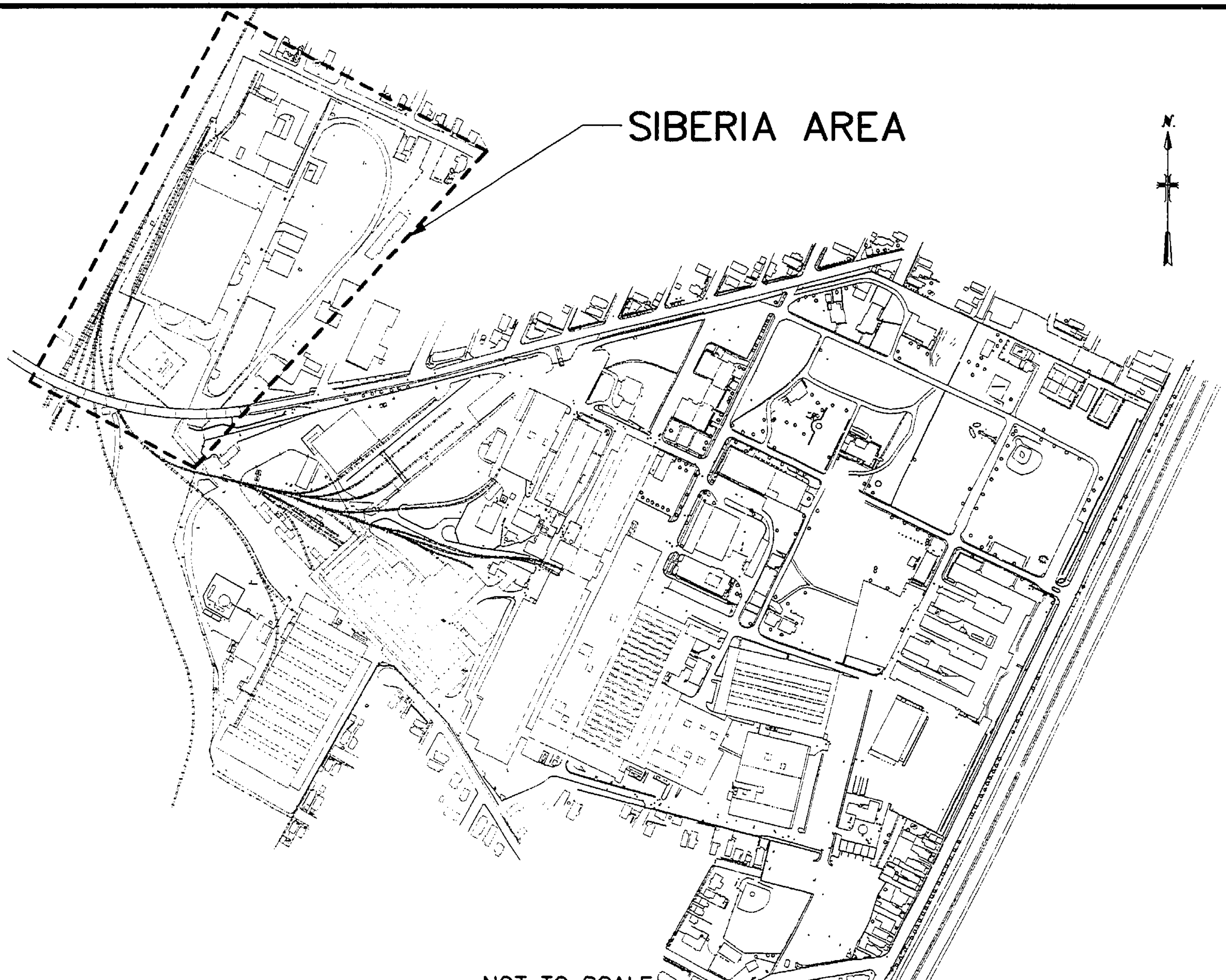
FIGURE 1-1



NOT TO SCALE

US Army Corps of Engineers

SIBERIA AREA LOCATION MAP

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

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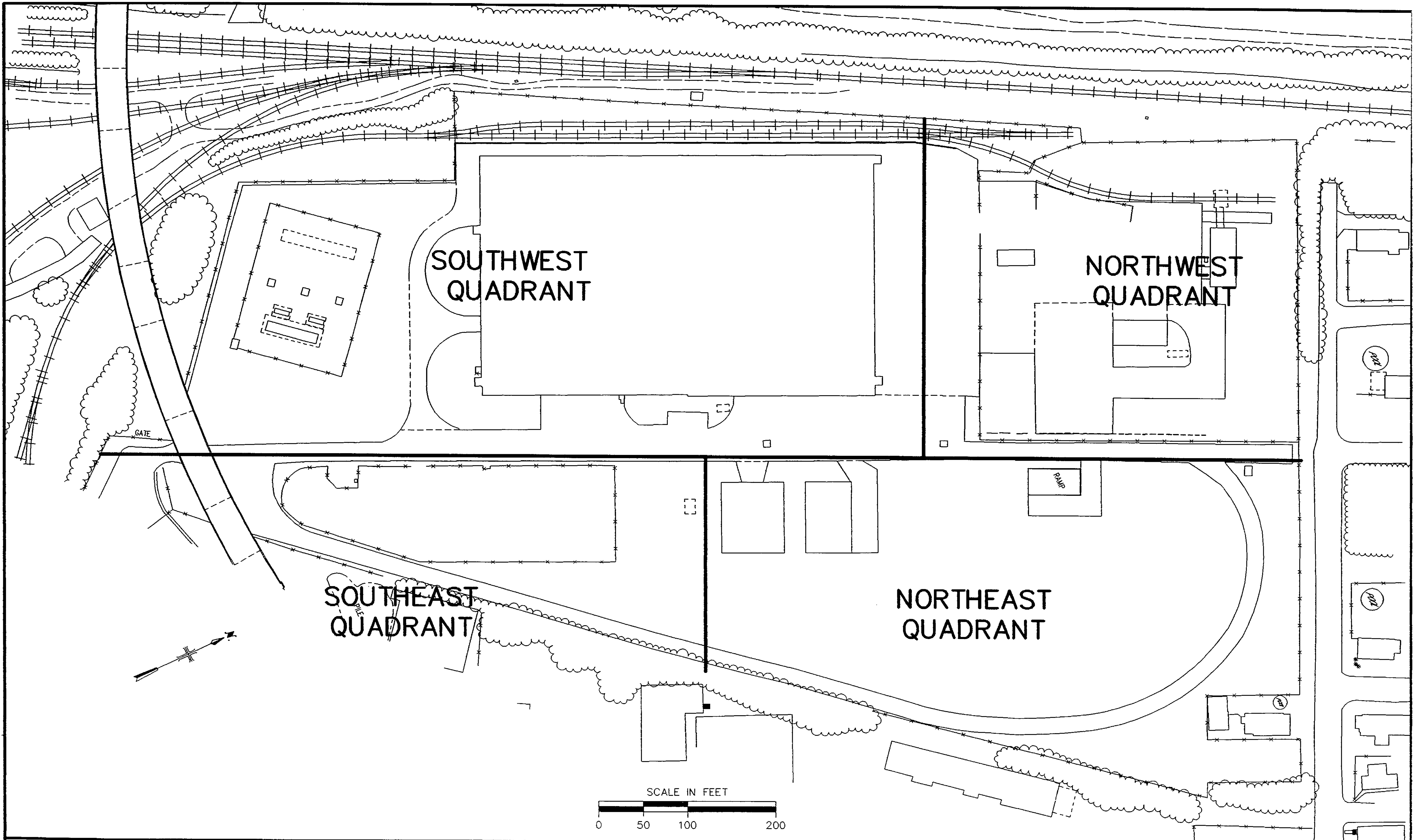
FIGURE 1-2



US Army Corps of Engineers

SIBERIA AREA
APPROXIMATE QUADRANT BOUNDRIES

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

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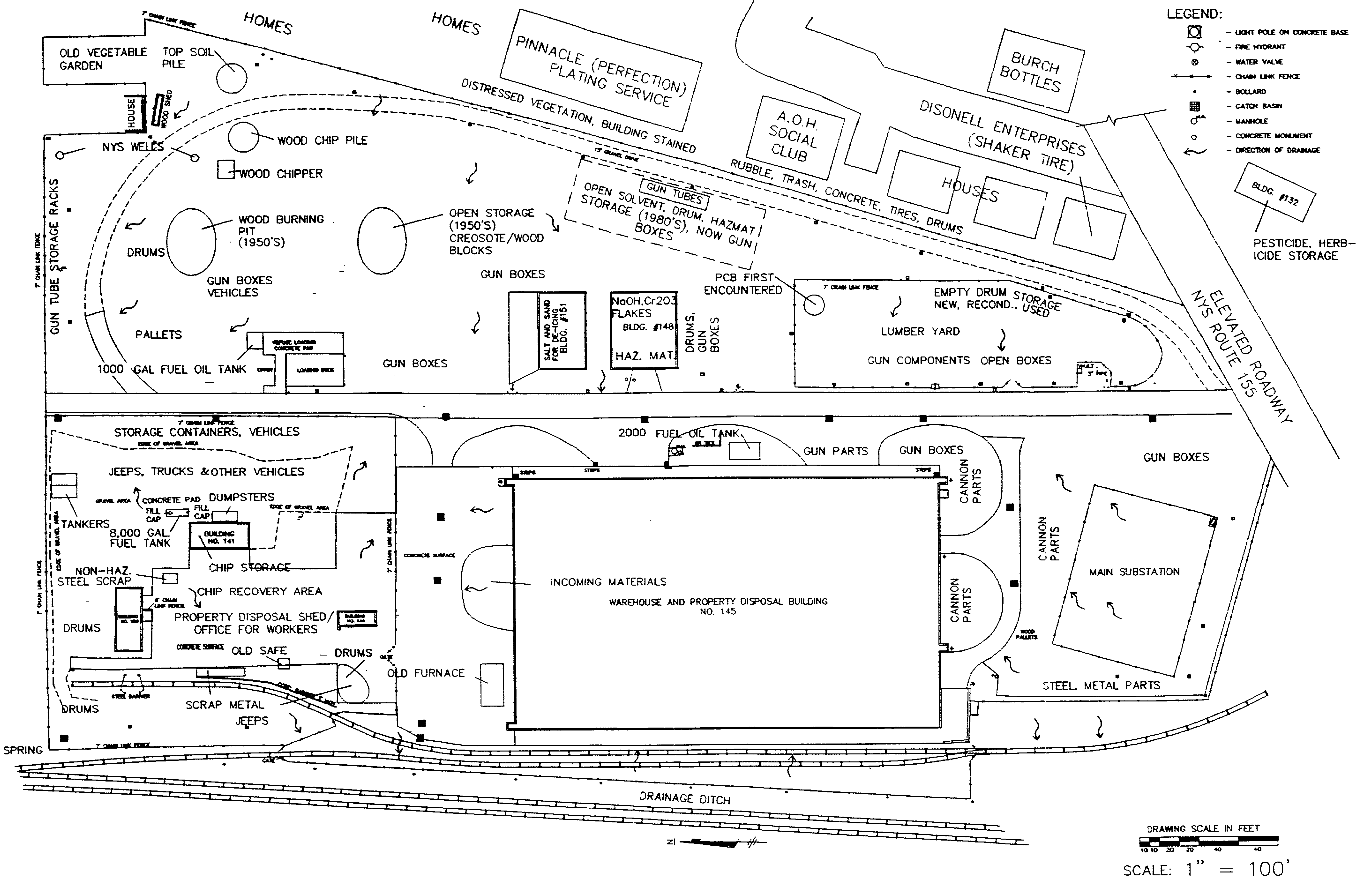
FIGURE 1-3



SOURCE: IMS R.F.I. WORKPLAN, 1994.

US Army Corps of Engineers

SIBERIA AREA
LAND USE AND SITE CONDITIONS

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

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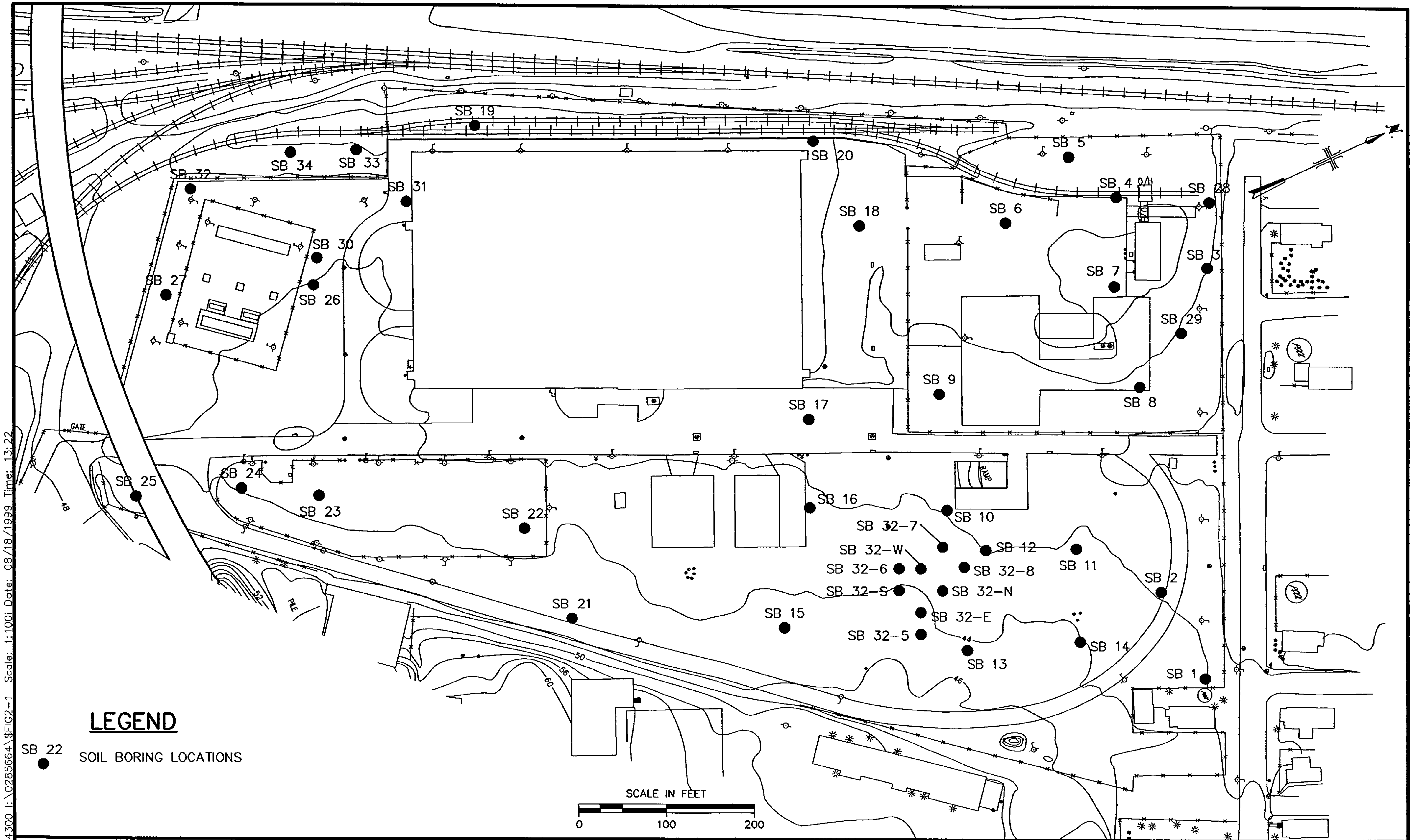
FIGURE 1-4



LEGEND

● SB 22 SOIL BORING LOCATIONS

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SOIL BORING LOCATIONS
SIBERIA AREA
WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

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FIGURE 2-1

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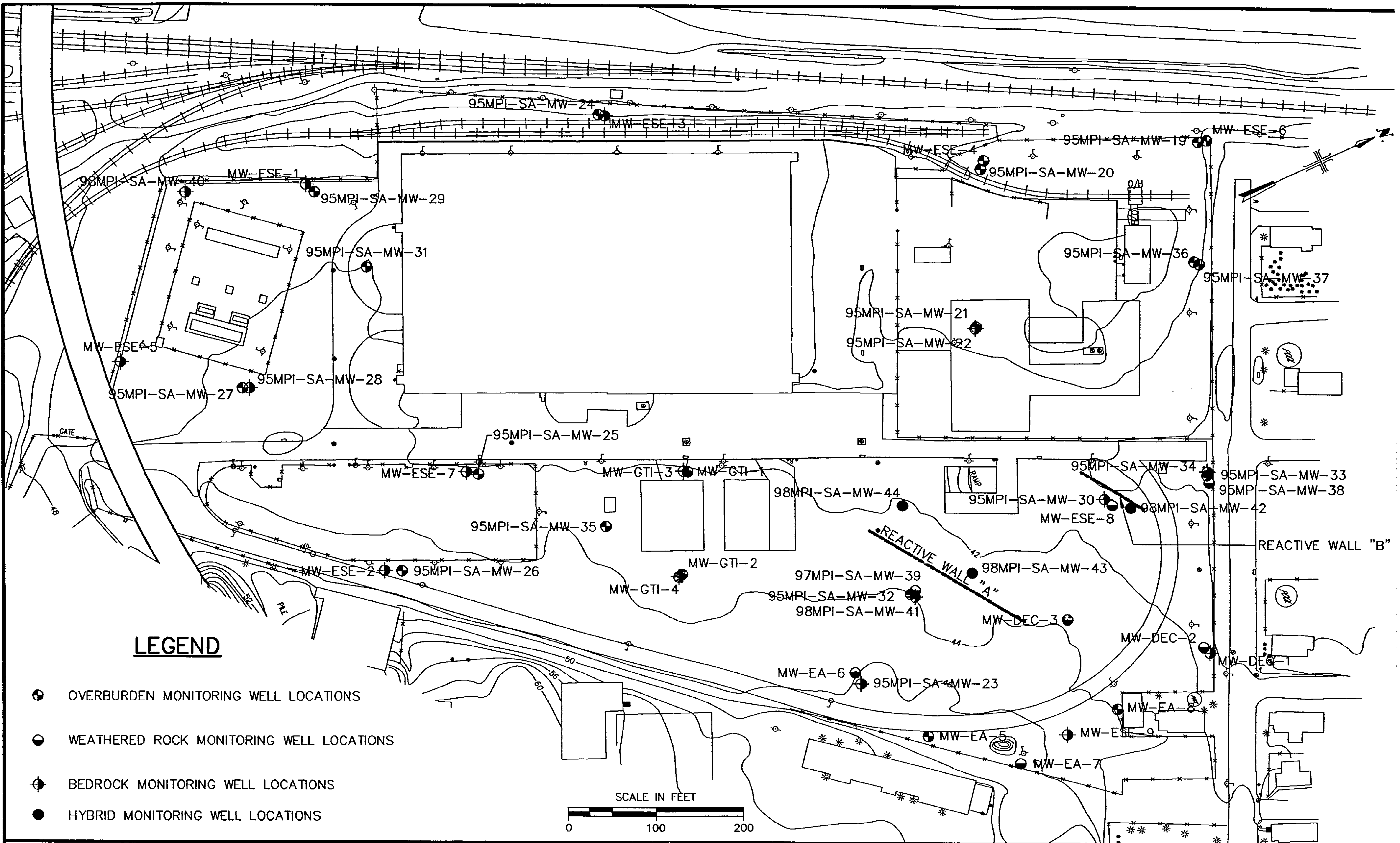
XREF: X587-02



LEGEND

- OVERBURDEN MONITORING WELL LOCATIONS
- WEATHERED ROCK MONITORING WELL LOCATIONS
- BEDROCK MONITORING WELL LOCATIONS
- HYBRID MONITORING WELL LOCATIONS

US Army Corps of Engineers

MONITORING WELL LOCATIONS

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

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FIGURE 2-2

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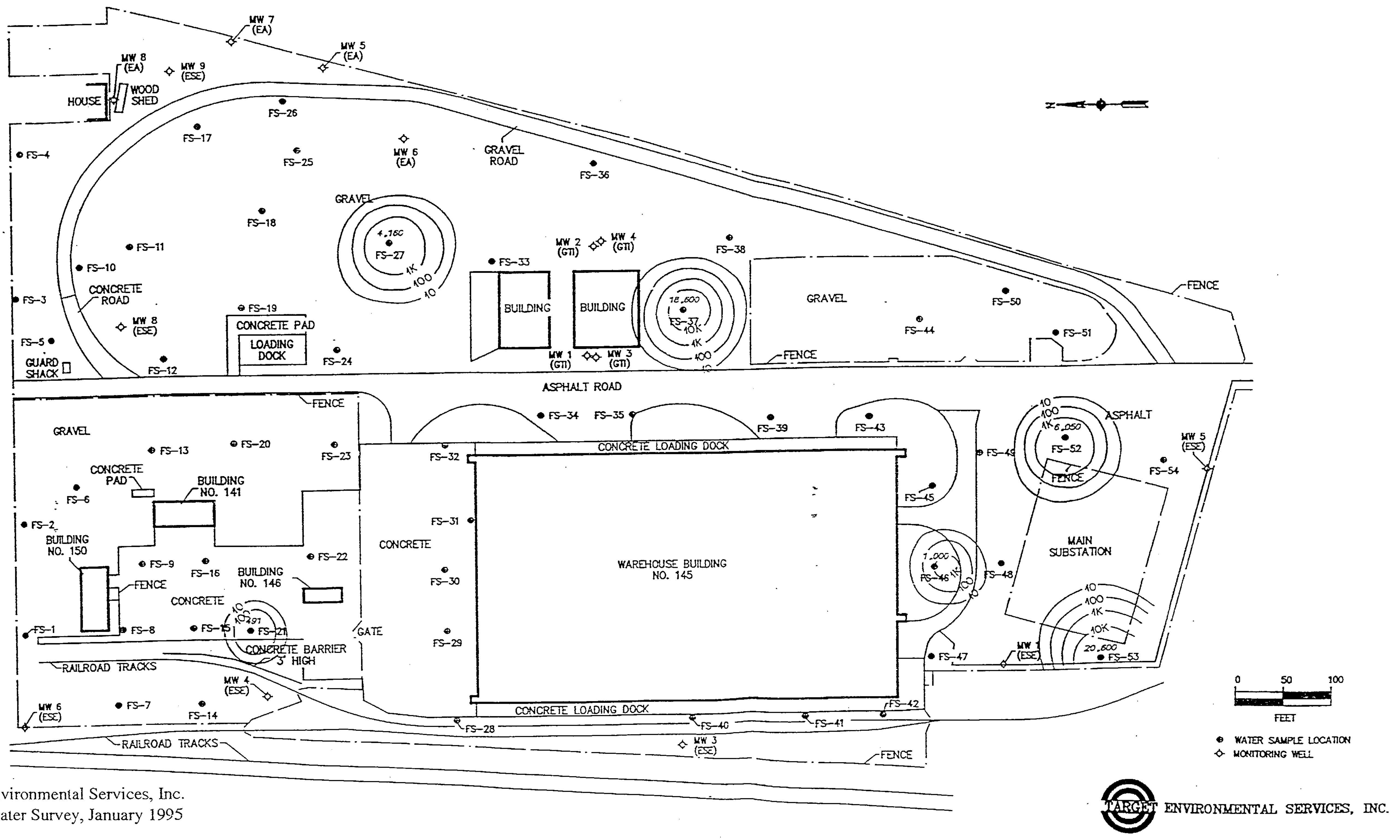

Source: Target Environmental Services, Inc.
Groundwater Survey, January 1995

TARGET ENVIRONMENTAL SERVICES, INC.

US Army Corps of Engineers

GROUNDWATER SCREENING – TOTAL VOCs
SIBERIA AREA

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

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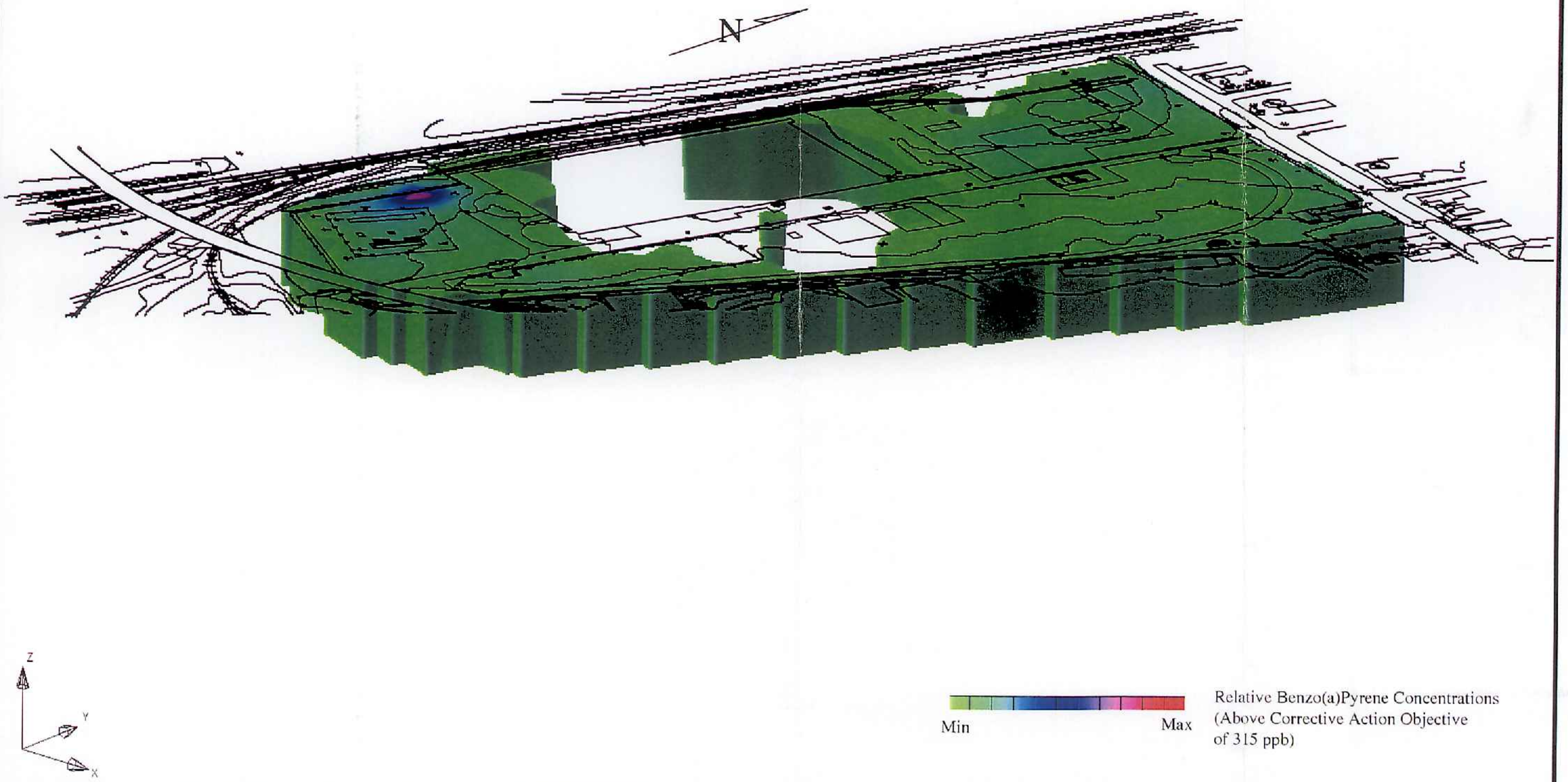
FIGURE 2-3



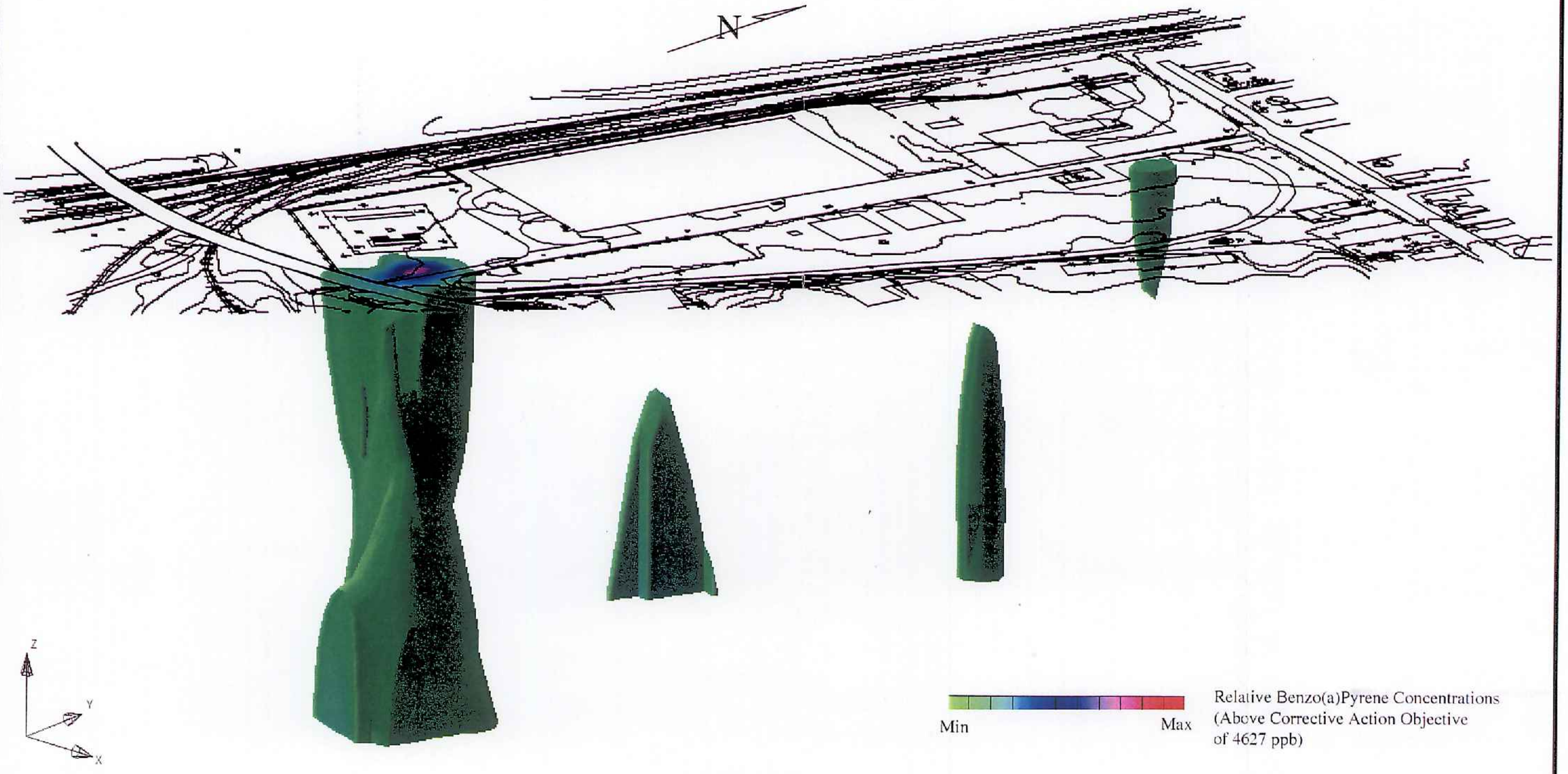
US Army Corps
of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Benzo(a)pyrene 0'-1' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-1



US Army Corps
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WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Benzo(a)pyrene 1'-6' Below Ground Surface

MALCOLM PIRNE, INC.

Figure 4-2

US Army Corps of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Benzo(a)pyrene 1'-2' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-3

US Army Corps of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Benzo(a)pyrene 2'-4' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-4

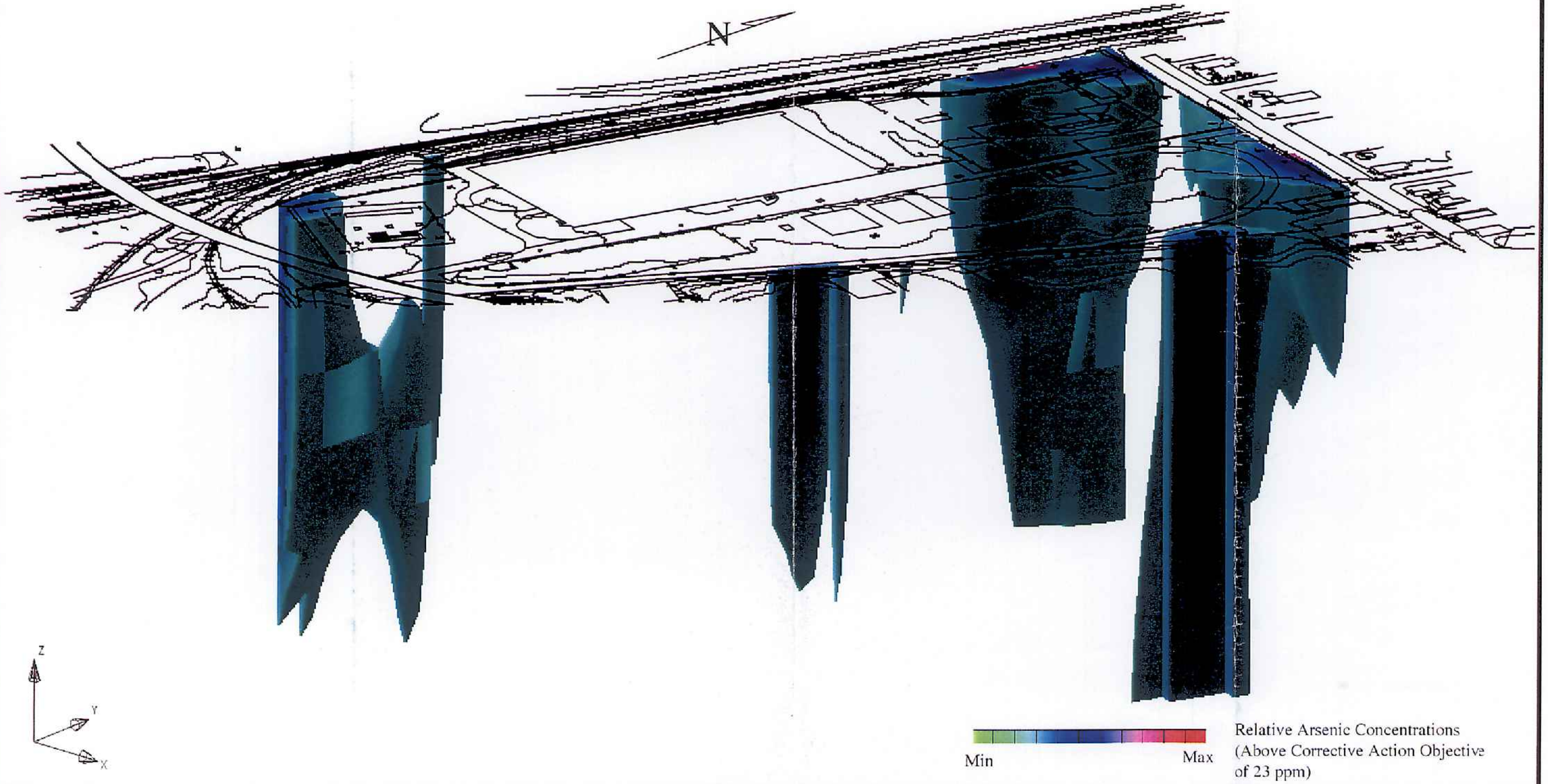
US Army Corps of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Benzo(a)pyrene 4'-6' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-5



US Army Corps
of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Arsenic 0'-6' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-6

US Army Corps of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Arsenic 0'-1' Below Ground Surface

MALCOLM PIRNE, INC.

Figure 4-7

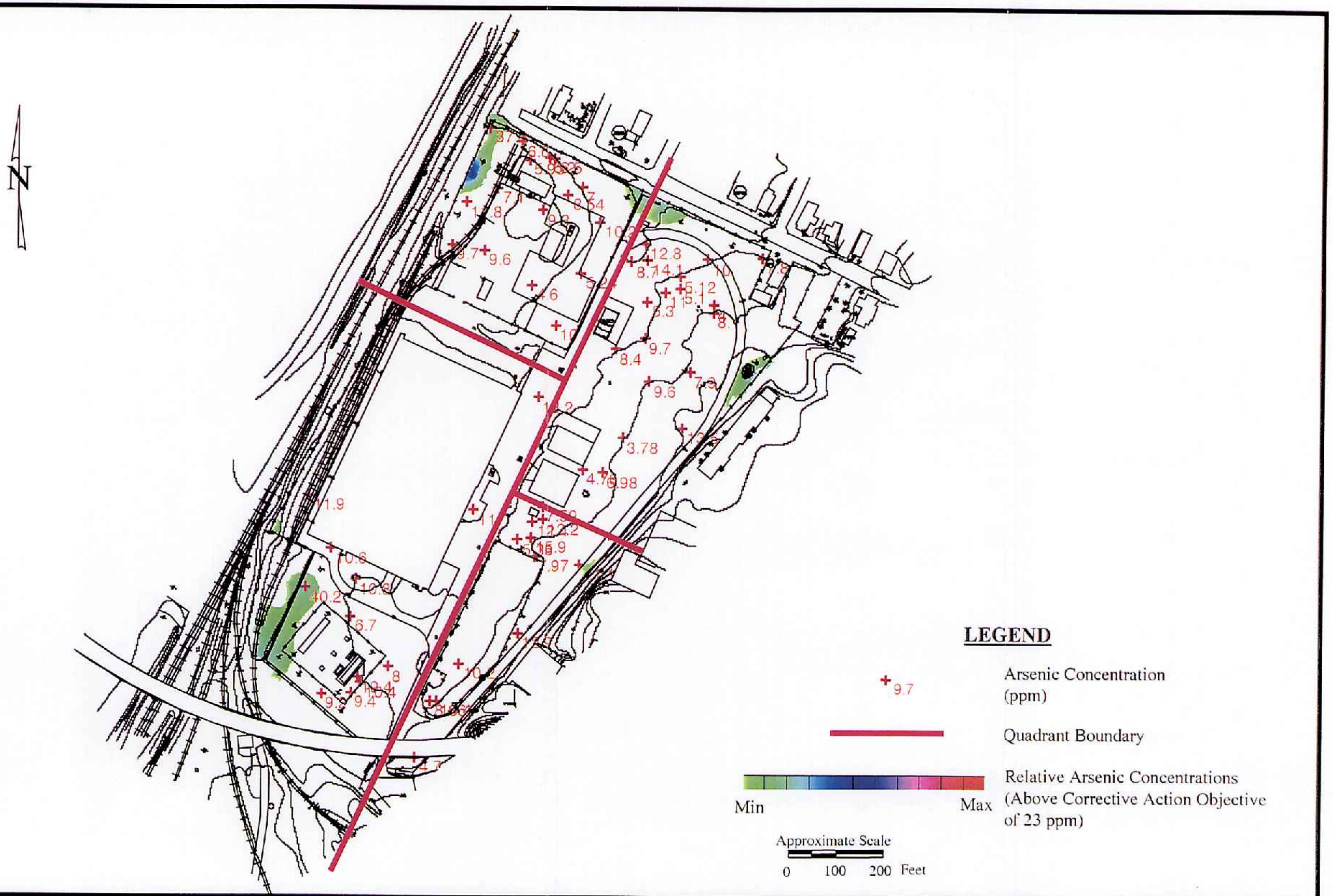
US Army Corps of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Arsenic 1'-2' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-8



US Army Corps
of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Arsenic 2'-4' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-9

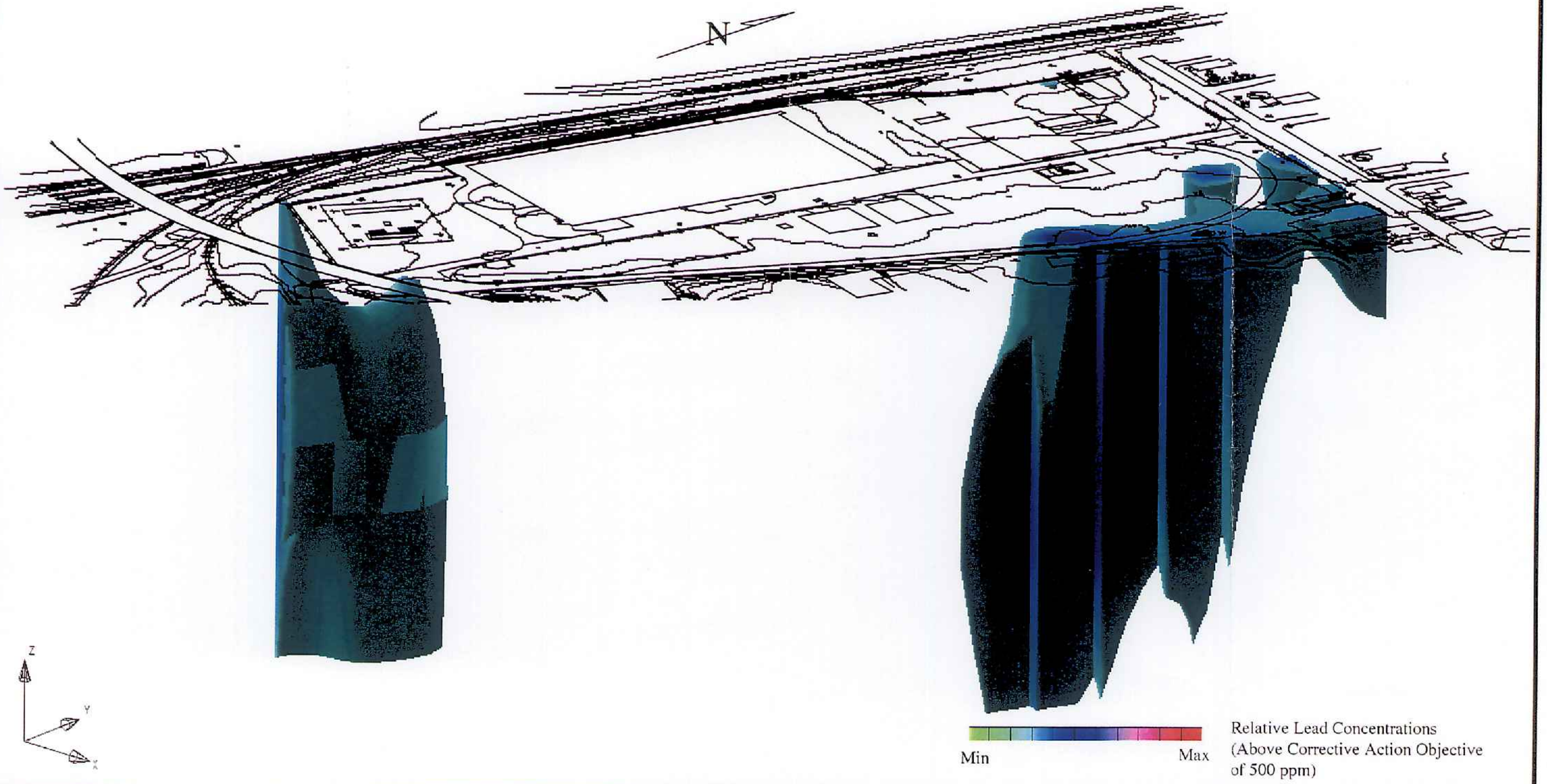
US Army Corps of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Arsenic 4'-6' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-10



US Army Corps
of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Lead 0'-6' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-11

US Army Corps
of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Lead 0'-1' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-12

US Army Corps of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Lead 1'-2' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-13

US Army Corps of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Lead 2'-4' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-14

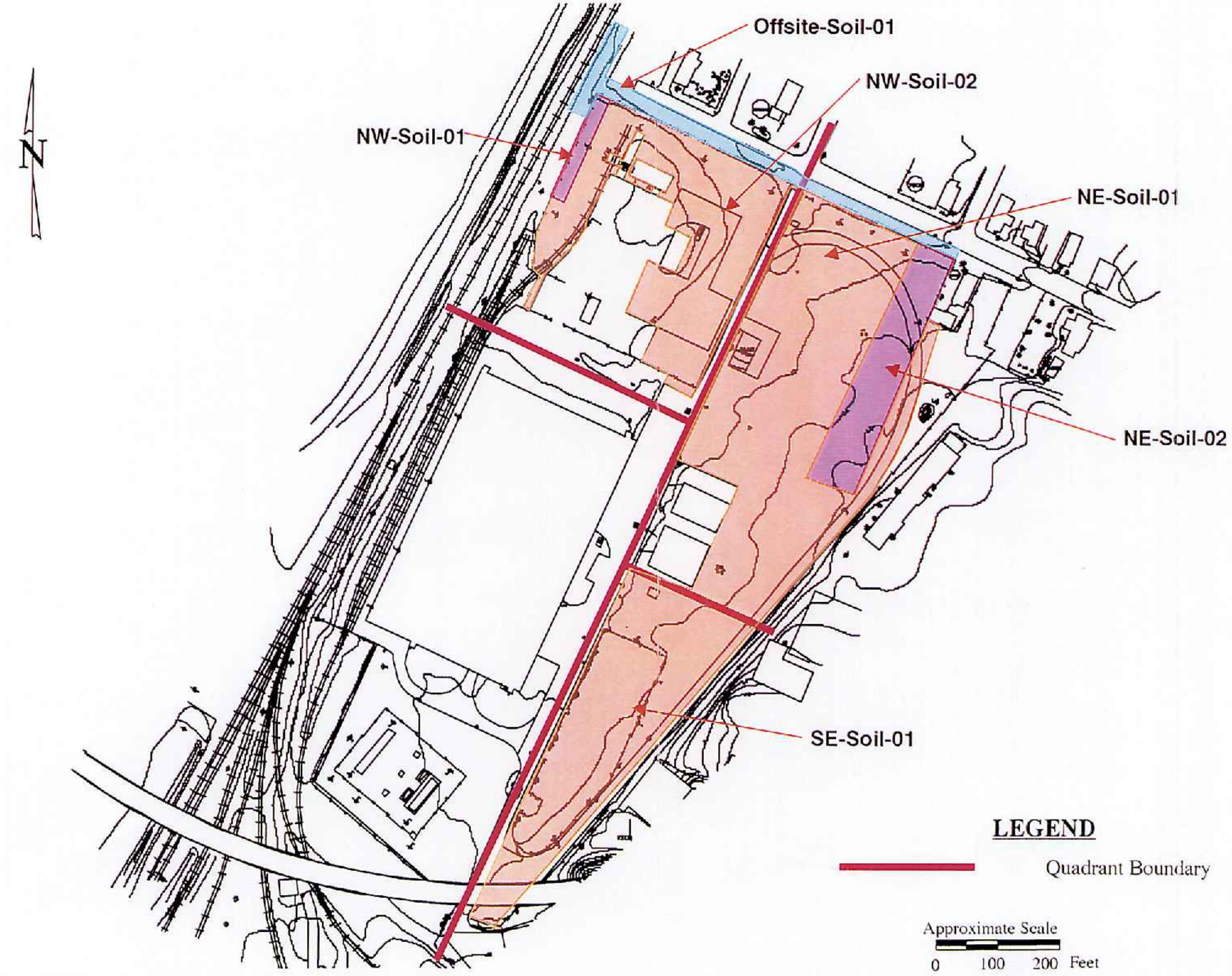
US Army Corps of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Lead 4'-6' Below Ground Surface

MALCOLM PIRNIE, INC.

Figure 4-15



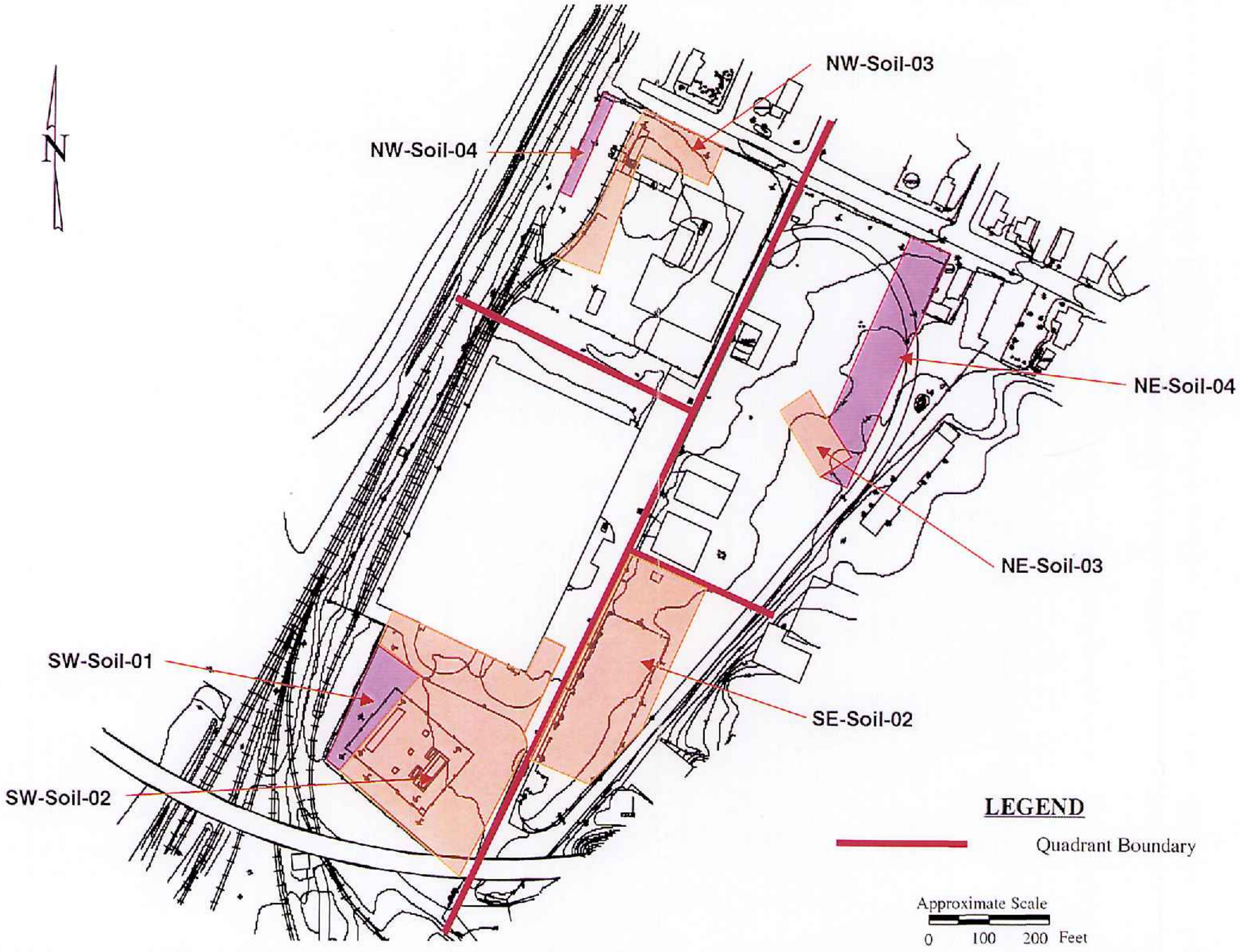
US Army Corps
of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Surface Soil AOCs

MALCOLM PIRNIE, INC.

Figure 4-16



US Army Corps
of Engineers

WATERVLIET ARSENAL
USACE CONTRACT NO. DACA31-94-D-0017

Siberia Area
Subsurface Soil AOCs

MALCOLM PIRNIE, INC.

Figure 4-17