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PHASE II CORRECTIVE MEASURES STUDY WORK PLAN IN-SITU REDUCTION OF HEXAVALENT CHROMIUM USING ZVI SOLID WASTE MANAGEMENT UNIT 70 (SWMU70) ZONE E WITH TRANSMITTAL CNC CHARLESTON SC
1/21/2002
CH2M HILL

PHASE II CORRECTIVE MEASURES STUDY WORK PLAN

In-Situ Reduction of Hexavalent Chromium Using ZVI
SWMU 70, Zone E

Charleston Naval Complex
North Charleston, South Carolina

SUBMITTED TO
U.S. Navy Southern Division
Naval Facilities Engineering Command

PREPARED BY
CH2M-Jones

January 2002

Revision 1
Contract N62467-99-C-0960
158814.ZE.PR.03

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January 21, 2002

Mr. David Scaturo
Division of Hazardous and Infectious Wastes
South Carolina Department of Health and
Environmental Control
Bureau of Land and Waste Management
2600 Bull Street
Columbia, SC 29201

Re: Phase II CMS Work Plan (Revision 1) – SWMU 70, Zone E

Dear Mr. Scaturo:

Enclosed please find two copies of the Phase II CMS Work Plan (Revision 1) for SWMU 70 in Zone E of the Charleston Naval Complex (CNC). This report has been prepared pursuant to agreements by the CNC BRAC Cleanup Team for completing the RCRA Corrective Action process.

The principal author of this document is Paul Favara. Please contact him at 352/335-5877, extension 2396, if you have any questions or comments.

Sincerely,

CH2M HILL

Dean Williamson, P.E.

cc: ✓Rob Harrell/Navy, w/att
Gary Foster/CH2M HILL, w/att

Certification Page for Phase II CMS Work Plan (Revision 1) — SWMU 70, Zone E

Pilot Study: In-Situ Reduction of Hexavalent Chromium Using Zero-Valent Iron

I, Dean Williamson, certify that this report has been prepared under my direct supervision. The data and information are, to the best of my knowledge, accurate and correct, and the report has been prepared in accordance with current standards of practice for engineering.

South Carolina

Permit No. 21428

Dean Williamson

Dean Williamson, P.E.

1/17/2002

Date

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B Analytical Data for Samples Collected during Phase I

C MSDS for ZVI Powder

D CH2M-Jones' Responses to SCDHEC Comments on the *Phase II CMS Work Plan for SWMU 70, Zone E (Revision 0)*, submitted October 2001

Acronyms and Abbreviations

BRAC	Base Realignment and Closure Act
CA	Corrective Action
CMS	Corrective Measures Study
CNC	Charleston Naval Complex
eV	electron volt
ft^2	square feet
ft bls	feet below land surface
HW	heavy wall
IDW	investigation-derived waste
kg	kilogram
µg/L	micrograms per liter
MNA	monitored natural attenuation
MSDS	material safety data sheet
MSL	mean sea level
NAVBASE	Naval Base
OD	outside diameter
PPE	personal protective equipment
PSIG	pounds per square inch gauge
RCRA	Resource Conservation and Recovery Act
SCDHEC	South Carolina Department of Health and Environmental Control
SWMU	solid waste management unit
TCE	trichloroethylene
TTA	target treatment area
VOC	volatile organic compound
ZVI	zero-valent iron

Section 1.0

1.0 Introduction

1.1 Purpose and Objectives of the Phase II CMS Work Plan

In 1993, Naval Base (NAVBASE) Charleston was added to the list of bases scheduled for closure as part of the Defense Base Realignment and Closure Act (BRAC), which regulates closure and transition of property to the community. The Charleston Naval Complex (CNC) was formed as a result of the dis-establishment of the Charleston Naval Shipyard and NAVBASE on April 1, 1996.

CNC Corrective Action (CA) activities are being conducted under the Resource Conservation and Recovery Act (RCRA); the South Carolina Department of Health and Environmental Control (SCDHEC) is the lead agency for CA activities at the site. All RCRA CA activities are performed in accordance with the Final Permit (Permit No. SC0 170 022 560).

In April 2000, CH2M-Jones was awarded a contract to provide environmental investigation and remediation services at the CNC. This Phase II Corrective Measures Study (CMS) Work Plan (subsequently referred to as a Pilot Study Work Plan) has been prepared by CH2M-Jones to document the basis for a pilot study at Solid Waste Management Unit (SWMU) 70 in Zone E of the CNC. The location of SWMU 70 within the CNC is presented in Figure 1-1.

The Phase I CMS Work Plan for SWMU 70 was submitted in December 2000; field work was completed in March and April 2001. The objective of the Phase I effort was to characterize the extent of hexavalent chromium contamination in groundwater at the site. The results of this effort are presented in Section 2.0 of this Pilot Study Work Plan.

The pilot study will evaluate the effectiveness of zero-valent iron (ZVI) in reducing hexavalent chromium in groundwater at SWMU 70.

The remediation of the hexavalent chromium in groundwater is not necessarily intended to be the final remedy for SWMU 70; however, implementation of the pilot study is expected to be compatible with the final remedy selected for SWMU 70.

After completion of the pilot study at this site, the RCRA CMS process will be followed to identify appropriate final remedial measures for SWMU 70, should additional corrective action be necessary.

This CMS WP (Revision 1) is a revised submittal of the CMS WP (Revision 0) of October 2001. Responses to regulatory comments pertaining to the Revision 0 submittal are presented in Appendix D.

1.2 Organization of the Phase II CMS Work Plan

This Phase II CMS Work Plan consists of the following sections, including this introductory section:

1.0 Introduction —Presents the purpose of the work plan and background information relating to the proposed investigation.

2.0 Site Characterization (Phase I) —Provides the results of the Phase I characterization effort.

3.0 Technical Approach — Describes the technical approach for completing the pilot study at SWMU 70.

4.0 Investigation-Derived Waste — Describes the procedures to be implemented for management of the investigation-derived waste (IDW).

5.0 Project Schedule —Provides a detailed outline of the schedule to be implemented during the pilot study.

6.0 References — Lists the references used in this document.

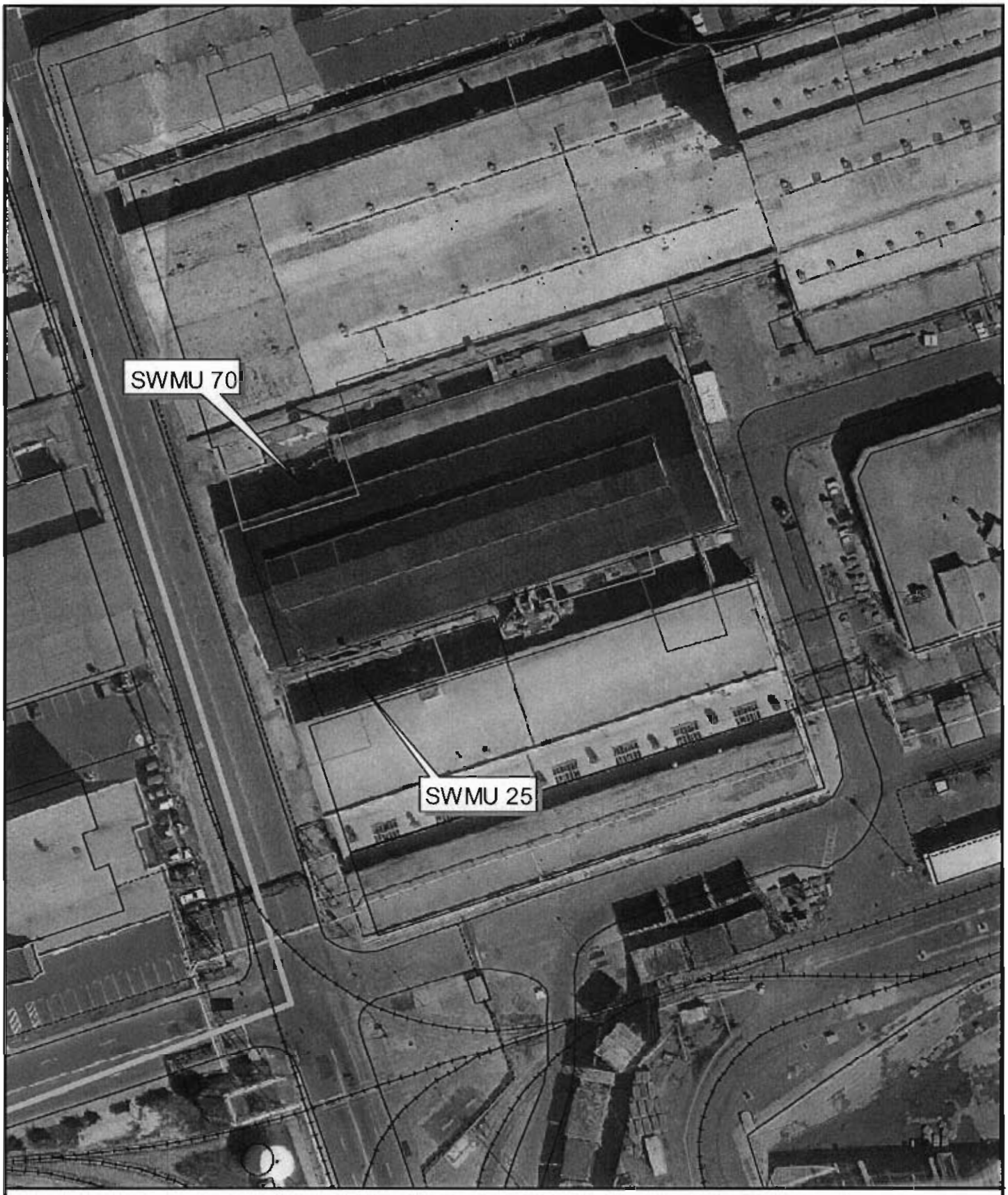
Appendix A contains the soil boring logs for samples collected at part of the Phase I investigation.

Appendix B contains laboratory data reported for the Phase I investigation.

Appendix C contains a material safety data sheet (MSDS) for the ZVI powder that will be used in the pilot study.

Appendix D contains CH2M-Jones' Responses to SCDHEC Comments on the *Phase II CMS Work Plan for SWMU 70, Zone E (Revision 0)*, submitted October 2001.

All tables and figures appear at the end of their respective sections.



Railroads
Roads
AOC Boundary
SWMU Boundary
Buildings

N

0 70 140 Feet

1 inch = 85.2188 feet

Figure 1-1
Aerial View
SWMU 25/70-
Charleston Naval Complex

CH2MHILL

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Section 2.0

2.0 Site Characterization (Phase I)

In March and April of 2001, CH2M-Jones completed an investigation of groundwater at SWMU 70. A total of 15 vertical profiles were completed and several groundwater samples were collected from each profile. Additionally, groundwater samples were collected from existing monitoring wells near the site.

Figure 2-1 shows the location of monitoring wells and vertical profile locations where groundwater sampling was conducted. Prior to collecting discrete groundwater samples, four soil borings (E070GP002, E070GP003, E070GP007, and E070GP009) were advanced to depths of approximately 24 to 35 feet below land surface (ft bls) to confirm the presence of the shallowest first aquitard/aquiclude below the water table. The locations of these borings are also presented in Figure 2-1. Logs for these borings are presented in Appendix A.

In general, approximately three different intervals were sampled from each vertical profile location. These three intervals have been categorized into the following elevation intervals:

- 0 to +2 feet mean sea level (ft msl) (referred to as interval A)
- -13 to -5 ft msl (referred to as interval B)
- -24 to -18 ft msl (referred to as interval C)

An aquitard has been interpreted at an elevation of approximately -24 ft msl.

Table 2-1 shows the parameters targeted for each groundwater sample. Monitored natural attenuation (MNA) parameters are presented in Table 2-2. Table entries that are highlighted in gray represent MNA parameters. Analytical data for groundwater samples collected for the Phase I investigation are reported in Appendix B. Hexavalent chromium concentrations reported in intervals A, B, and C are presented in Figures 2-2, 2-3, and 2-4, respectively.

TABLE 2-1
Analysis of Collected Groundwater Samples
Phase II CMS Work Plan, SWMU 70, Zone E, Charleston Naval Complex

Samples	Analysis
E070VP001-E070VP013	Dissolved Chromium, Hexavalent Chromium, Cadmium
E025GW001, E025GW002, E025GW004;E070GW002, E549GW001	Total and Dissolved Chromium, Hexavalent Chromium, Cadmium
	MNA Parameters (Refer to Table 2-2)
E025GW003, E070GW001, E07GW01D, E549GW003, E549GW002	Total and Dissolved Chromium, Hexavalent Chromium, Cadmium
	MNA Parameters (Refer to Table 2-2)
	VOCs

MNA Monitored natural attenuation
VOC Volatile organic compound

TABLE 2-2
Analytical Methods and Data Use
Phase II CMS Work Plan, SWMU 70, Zone E, Charleston Naval Complex

Analysis	Method	Comments	Data Use	Field or Fixed-Base Laboratory
Total and Dissolved Chromium, Hexavalent Chromium and Cadmium	Chromium-Total SW-846 7196A; Cadmium SW-846 6010; Hexavalent Chromium SW-846 6010	Determine extent of Chromium and Hexavalent Chromium contamination. Cadmium exceeded MCLs at 025GW003; limited Cadmium data will be collected around this area	Data will be used to evaluate potential remedial approach(es) to be field tested as part of pilot study	Fixed-base
Oxygen*	DO Meter calibrated in the field according to the supplier's specifications		Concentrations < 0.5 mg/L generally indicate an anoxic pathway	Field
Nitrate	Ion Chromatography Method E300		Substrate for microbial respiration if oxygen is depleted	Fixed-Base
Soluble Manganese [MN (II)]	Colorimetric Hach Company Method 8149	Filter if turbidity interferes with analysis	May indicate an anoxic degradation process due to depletion of oxygen, nitrate, and manganese	Field
Ferrous Iron [FE(II)]	Colorimetric Hack Company Method 8146	Filter if turbidity interferes with analysis.	May indicate an iron-reducing environment	Field
Sulfate	IC Method E300		Substrate for anoxic microbial respiration	Fixed-Base
Hydrogen Sulfide	Color Disk methylene Blue Method	Hack Catalog Number 2238-01	The presence of H2S suggests a sulfate-reducing environment	Field
Methane	SW-846 method 3810 Modified		The presence of CH4 suggests biodegradation via methanogenesis	Fixed-Base

TABLE 2-2
Analytical Methods and Data Use
Phase II CMS Work Plan, SWMU 70, Zone E, Charleston Naval Complex

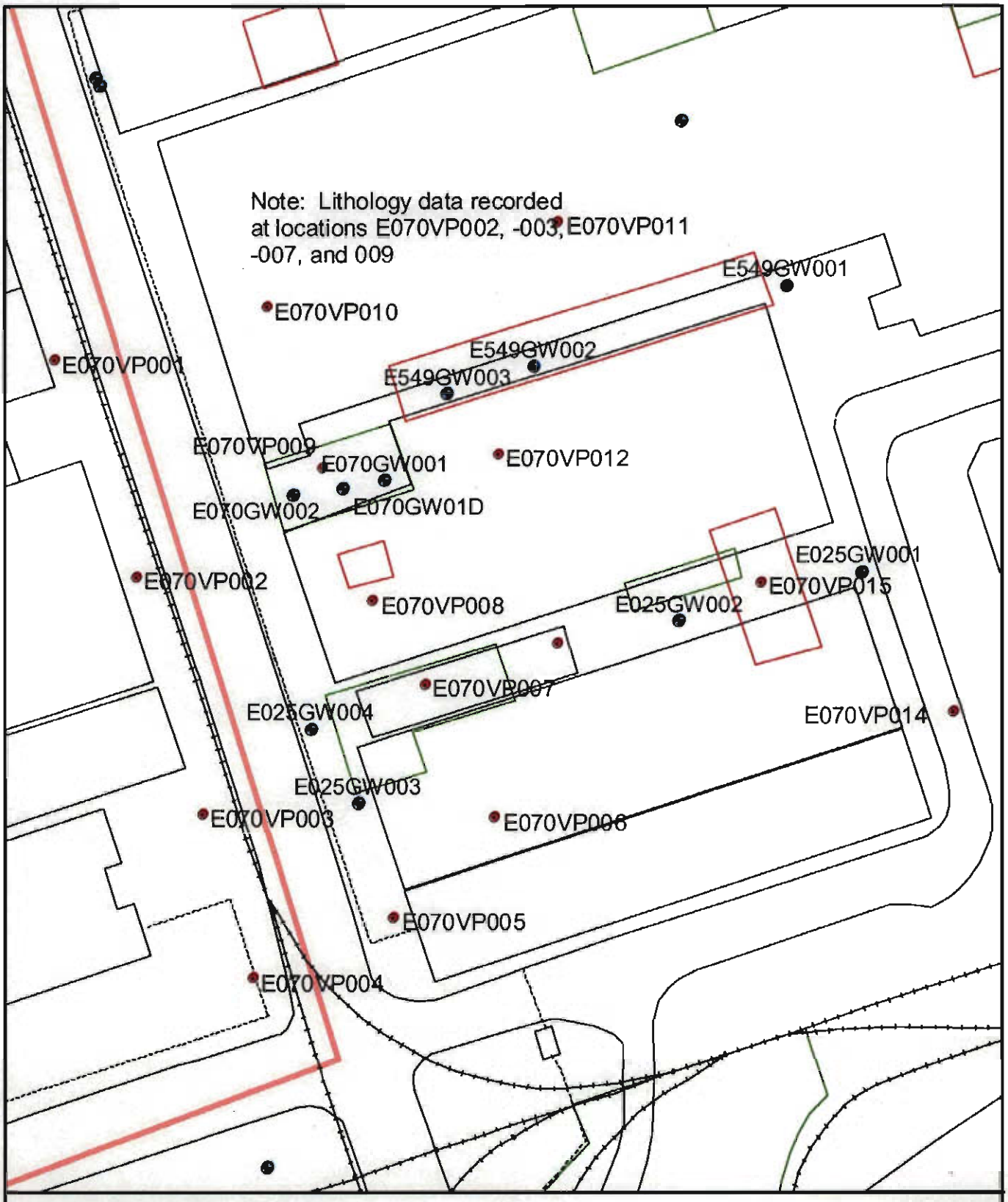
Analysis	Method	Comments	Data Use	Field or Fixed-Base Laboratory
Oxidation Reduction Potential (ORP)	ASTM Method A2580B	Measurements made with electrodes and meter; protect sample from oxygen. Report results against the hydrogen electrode (Eh) by adding a correction factor specific to the electrode used	The ORP of groundwater reflects the relative oxidizing or reducing nature of the groundwater system. ORP is influenced by the nature of the biologically mediated degradation of contaminants, and may range from 800 mV (oxygenated) to less than –400 (strongly reducing)	Field
pH	Field probe with direct-reading meter calibrated in the field according to the supplier's specifications		Aerobic and anoxic processes are pH-sensitive; ablotic reduction of chromium is pH - sensitive	Field
Temperature	Field Probe with direct-reading mater			Field
Conductivity	E120.1/SW-846 Method 9050, direct meter reading		General water quality parameters used as a marker to verify that site samples are obtained from the groundwater system	Field
Hydrogen	Equilibration with gas; determined with reduction gas detector (Microseeps)		Determine terminal electron accepting process. Under biotic conditions, hydrogen may act as an electron donor	Fixed-Base

* Table entries that are highlighted in gray represent MNA parameters.

DO Dissolved oxygen

MCL Maximum contaminant level

Mg/L Milligram per liter



Vertical Profile Locations
Groundwater Well
Railroads
Roads
AOC Boundary
SWMU Boundary
Buildings

N

0 60 120 Feet

Figure 2-1
Groundwater Sample Locations
SWMU 25/70 and Area
Charleston Naval Complex

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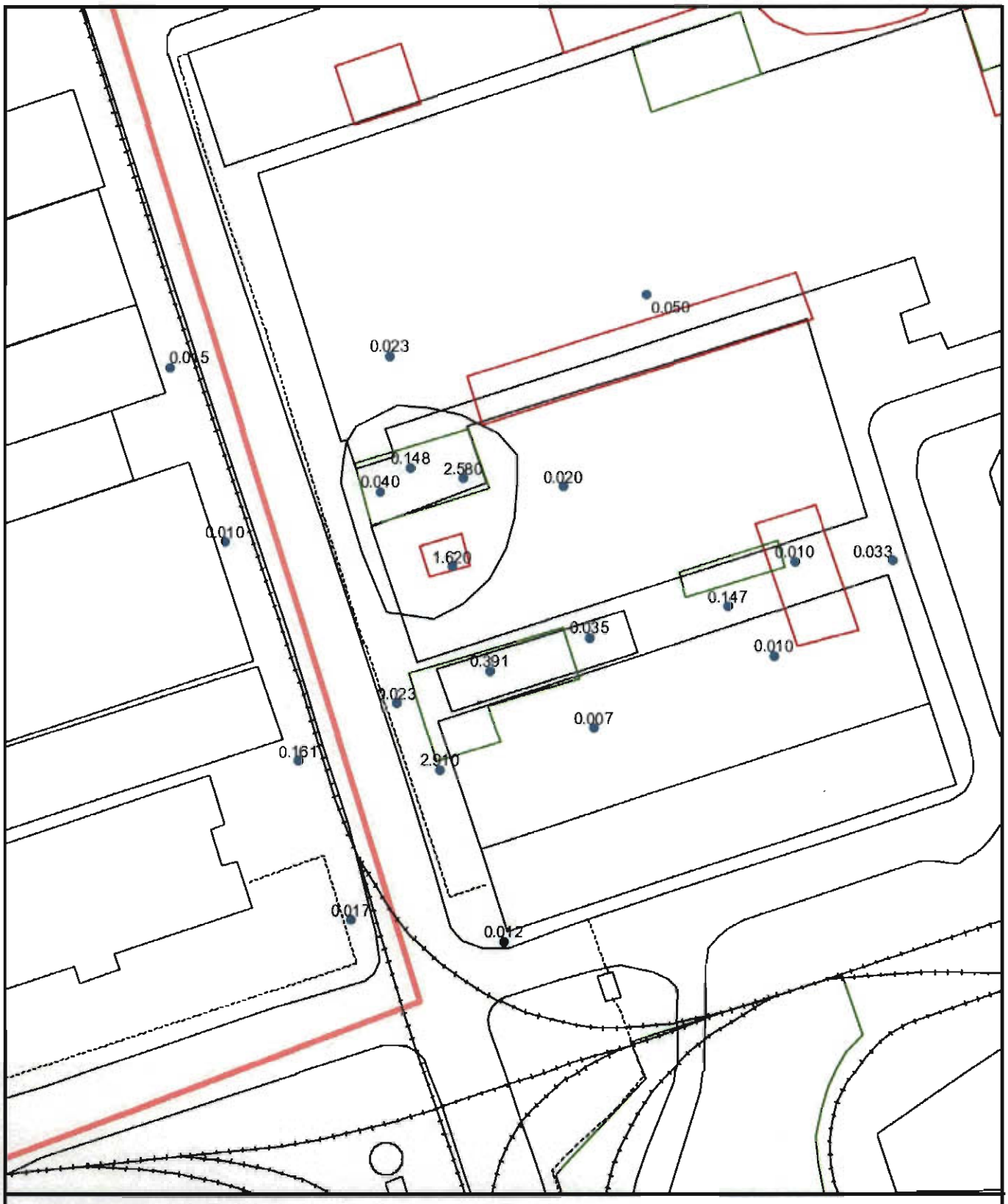

Samples at 0 to +2 ft MSL, mg/L
Roads
AOC Boundary
SWMU Boundary
Buildings
Target Treatment Zone

N

0 70 140 Feet

1 inch = 84.8655 feet

Figure 2-2
Hexavalent Chromium
0 to +2 FT-MSL
Charleston Naval Complex

CH2MHILL

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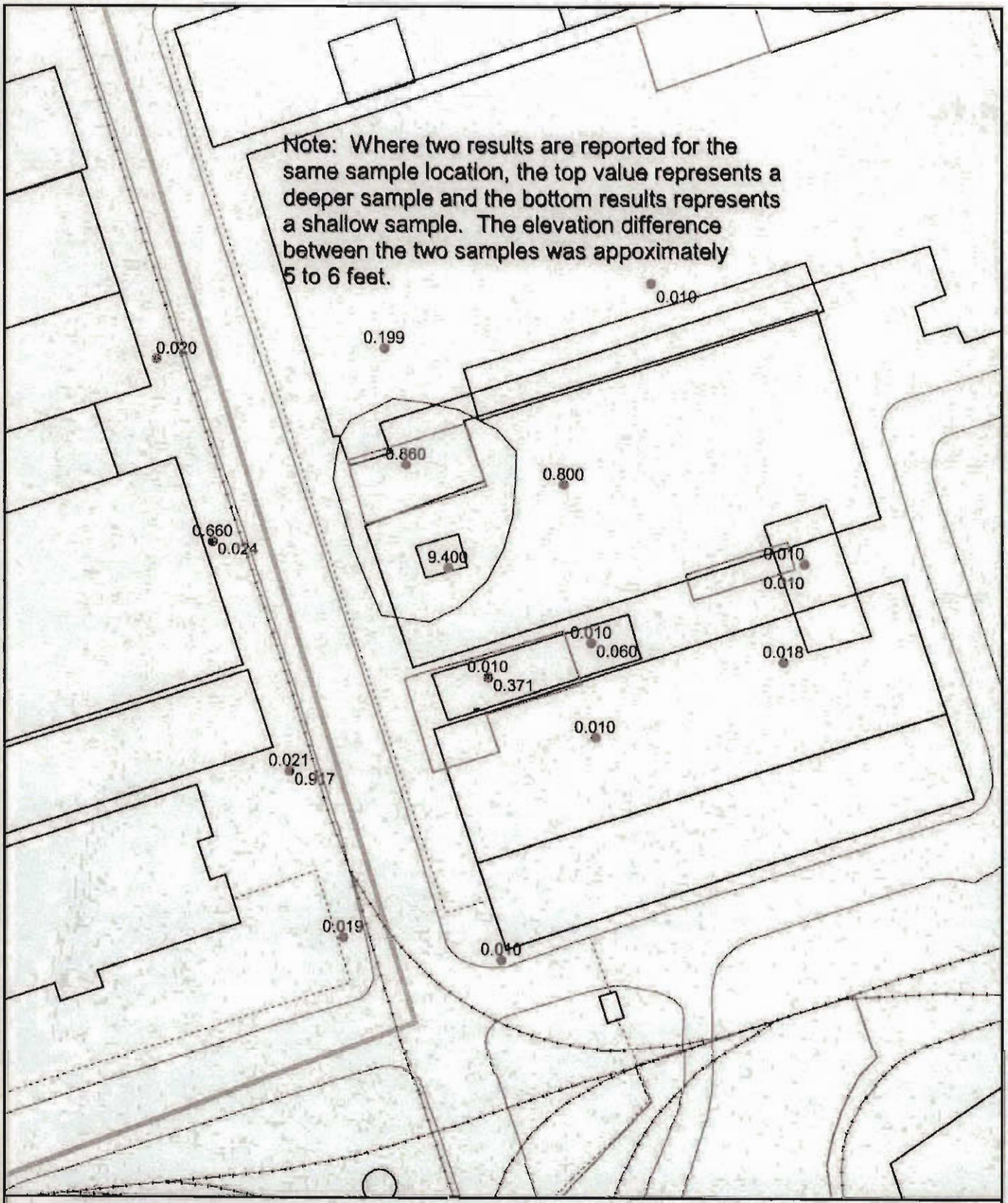

Samples at -13 to - 5 ft MSL, mg/L
Roads
AOC Boundary
SWMU Boundary
Buildings
Target Treatment Zone

N

0 60 120 Feet

1 inch = 81.3988 feet

Figure 2-3
Hexavalent Chromium
-13 to -5 FT-MSL
Charleston Naval Complex

CH2MHILL

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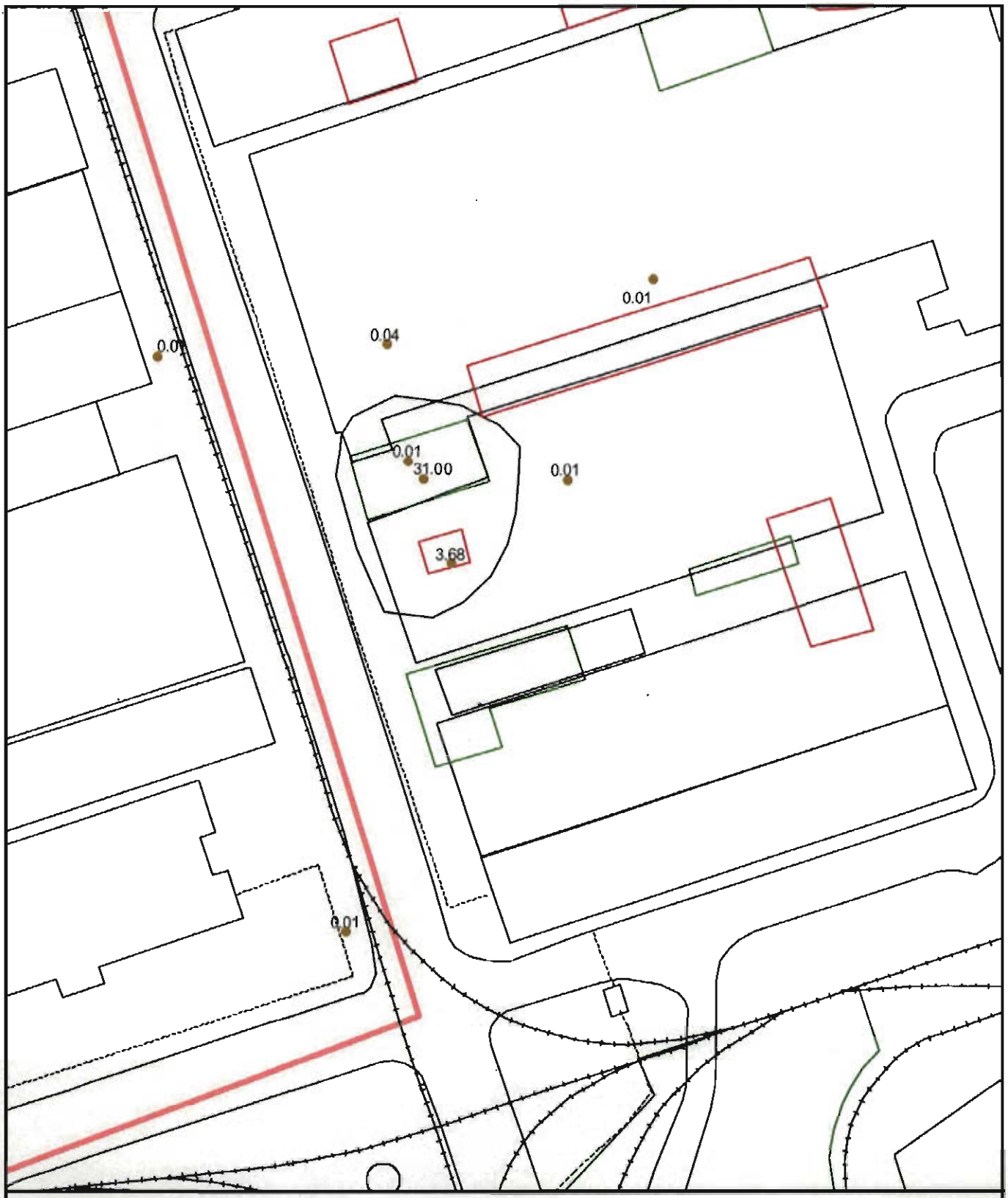

Samples at -24 to -18 ft MSL, mg/L
Roads
AOC Boundary
SWMU Boundary
Buildings
Target Treatment Zone

N

0 60 120 Feet

1 inch = 81.3988 feet

Figure 2-4
Hexavalent Chromium
-24 to -18 FT MSL
Charleston Naval Complex

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Section 3.0

3.0 Technical Approach

This pilot study will evaluate the effectiveness of ZVI in reducing concentrations of hexavalent chromium in groundwater at SWMU 70. ARS Technologies (Highland Park, NJ) has been contracted by CH2M-Jones to implement the pilot study at SWMU 70. The sections below address the study's technical components:

- The ARS Ferox^{SM} process
- Applicability of the Ferox^{SM} process to hexavalent chromium reduction
- Overview of the injection method
- Treatment goals
- Areas to be treated
- Well installation and layout
- Ferox^{SM} Injection Operations
- Ferox^{SM} Injection
- Pneumatic fracturing effects on nearby structures
- Injection monitoring
- Post-injection monitoring
- Reporting
- Permitting

3.1 Ferox^{SM} Process

ARS' Ferox^{SM} technology is a patented in-situ subsurface remediation process and is applicable to the treatment of soluble metals. The Ferox^{SM} technology involves the subsurface injection and dispersion of specific quantities of highly reactive ZVI powder into saturated or unsaturated contamination zones.

In-situ chemical reduction of organic and inorganic compounds using ZVI has been extensively studied in the form of permeable reaction walls or funnel/gate systems. However, iron walls rely exclusively on the flow of groundwater and treat only soluble phase compounds. These systems are not capable of treating source area contaminants, are limited in depth by which they can be applied, and are not implementable when buildings or utilities are present. The Ferox^{SM} technology presents a breakthrough from such limitations.

ARS' expertise in subsurface injections and fracturing provides a unique method of applying the ZVI to overcome the limitations of conventional technology through direct access and remediation of the metals existing in the subsurface. A significant advantage of the Ferox^{SM} process is that it provides the ability to increase iron loading in areas of higher contaminant concentrations. As a result, in-situ treatment times are dependent upon average contaminant concentrations rather than being limited by the highest levels present.

The ZVI that ARS uses in its Ferox^{SM} application is a 98+% pure reduced powder imported from Japan. The powder's particle size, shape, and carbon content result in an extremely reactive material (see the MSDS in Appendix C). As a result of the powder's small particle size, it has a higher surface area to volume ratio, and thus greater reactivity, as compared to cheaper, less pure domestic-grade iron powders.

3.2 ZVI Reduction of Cr^{+6}

When naturally occurring in groundwater, chromium occurs in two states, Cr3+ and Cr6+. The ionic state of chromium is strongly dependent on the pH and E_h of the groundwater. The Cr3+ ionic state exists as $Cr(OH)^{2+}$ in the pH range of 4 to 6.5, and exists as an insoluble hydroxide $Cr(OH)_3$ when the pH is approximately 6.5 to 10.5.

Cr6+ species are more likely present in alkali and aerobic environments. In groundwater, Cr6+ exists as oxyanions $HCrO_4^-$ (dichromate) at pH less than 6 and CrO_4^{2-} (chromate) at pH greater than 6. Because Cr6+ species are charged negatively, their sorption onto most soil particles (having the same negative charge) is poor and decreases at higher pH values. These chromate oxyanions are of greatest environmental concern due to their toxic and carcinogenic properties and their greatly increased subsurface mobility when compared to a relatively less toxic and immobile Cr3+ species.

Redox reaction with ARS' Ferox^{SM} ZVI powder involves Fe^0 oxidation with dissolved oxygen and subsequent chromate ion reduction with Fe (II) cations, as shown in equations (1) and (2) below:

$$2Fe^0 + O_2 + H_2O = 2Fe^{2+} + 4OH^- \qquad (1)$$

$$Fe^{2+} + CrO_4^{2-} + 4H_2O = Fe(OH)_3 + Cr(OH)_3 + 2OH^- \qquad (2)$$

Standard electrode potentials at 25°C are 409 mV for the reaction $Fe^0 \rightarrow 2e^- + Fe^{2+}$, -0.771 mV for the reaction $Fe^{2+} \rightarrow Fe^{3+} + e^-$, and 36 mV for the reaction and $Fe^0 \rightarrow Fe^{3+} + 3e^-$. The ZVI iron provides a source of ferrous iron without having to introduce a ferrous salt, such as ferrous sulfate or ferrous chloride. The reaction of ferrous iron alone has sufficient

electrochemical reduction potential to reduce Cr(VI) to the insoluble Cr3+; however, the ZVI provides the additional 440 mV for reduction of Cr6+, without introducing other anions into the subsurface system.

Reactions (1) and (2) increase pH of the system and generate insoluble Cr3+ hydroxide or solid solution $(Cr_x Fe_{1-x})(OH)_3$ as a result of the chromate reduction. In most cases, the hydroxide that is created is buffered by the soil in the system.

Once reduced, Cr3+ is significantly more stable than Cr6+ as it forms complexes with ferrous iron and has the tendency to precipitate out of solution. The reversal of the chromium oxidative state from trivalent to hexavalent is highly unlikely and can only occur under extreme oxidizing conditions not expected to be encountered under natural conditions at SWMU 70.

3.3 Ferox^{SM} Injection Method

A critical component of the proposed in-situ chemical reduction of Cr^{+6} is ensuring that the ZVI is distributed within the subsurface in such a manner to initiate and transfer electrons required to reduce the Cr^{+6} to Cr^{+3}. To accomplish this, ARS will incorporate a Pneumatic Fracturing based delivery approach for the emplacement of the iron powder. The emplacement method is equally as important as the chemical reduction mechanism since the heterogeneous geology at SWMU 70 presents significant limitations for conventional hydraulic injection methods.

Pneumatic Fracturing is a patented process in which a gas is injected into the subsurface at pressures that exceed the combined overburden pressure and cohesive soil strength of the geologic matrix, and at flow rates that exceed the effective permeability of the undisturbed soil. The result is the propagation of fractures outward from the injection well to distances of 20 to 25 feet. The use of Pneumatic Fracturing will be critical to the in-situ treatment process since it will allow for effective permeability enhancement of the clay lenses, sandy silts, and cohesive materials to occur, and reduces geologic heterogeneities present within the subsurface while emplacing the reactive ZVI in the subsurface.

The ZVI slurry is fed directly into the gas stream aboveground and becomes atomized in the process gas. Relatively low pressures (50 to 100 pounds per square inch gauge [psig]) are needed to emplace the material within the subsurface. An integrated Pneumatic Fracturing/Ferox^{SM} atomization assembly consists of pneumatic packers straddling a 360-degree injection nozzle, creating a discrete target interval of 20 to 30 inches (the actual

injection interval will be finalized in the field). ARS' current commercial equipment is capable of injecting up to 50 gallons of ZVI slurry per minute.

3.4 Treatment Goals

The goal of the pilot study will be to determine if ZVI can reduce concentrations of hexavalent chromium in groundwater to levels below 100 micrograms per liter (µg/L).

3.5 Target Treatment Area

The target treatment area (TTA) for the pilot study is presented in Figure 3-1. The footprint area is approximately 12,000 square feet (ft^2). The TTA is also identified in Figures 2-2 through 2-4. The footprint of the TTA encompasses most locations where hexavalent chromium was reported at levels greater than the treatment goal. The CMS will address other locations that exceed the treatment goal.

The full saturated zone inside the TTA will be targeted for treatment, to a maximum depth of approximately 35 ft bls (-39 ft msl), or to the top of the Ashley Formation. The depth of the Ashley Formation was determined to be between 23 and 35 ft bls in borings E070VP002, E070VP003, E070VP007, and E070VP009. The elevation of the land surface is approximately 4 ft msl.

3.6 Bench-Scale Treatability Testing

In order to properly design the Ferox^{SM} application, groundwater and soil samples will be collected for baseline analysis and use in bench-scale treatability testing. Baseline information is necessary to confirm sediment and shallow groundwater conditions at the site, and to provide samples for the treatability study in bench-scale tests.

As part of the field sampling, ARS personnel will mobilize to SWMU 70 to collect representative groundwater and soil samples. Locations for soil samples will be cleared of utilities by CH2M-Jones prior to mobilization. These samples will be used in the treatability study, which will be used to derive iron loading rates for the field implementation. Approximately 10 to 15 L of groundwater and 5 to 10 kilograms (kg) of soil will be required for the treatability study, which will be conducted at NJAL laboratories in Pennington, NJ.

Past studies of Cr6+ (hexavalent chromium) with iron powder have indicated that mass ratios of 1,000:1 and 4,000:1 iron to chromium have been successful in reducing concentrations by 95 percent in 30 days. Based on these results, it is anticipated that a mass

ratio falling within these two limits will be effective at reducing hexavalent chromium concentrations at SWMU 70 to below target levels of 100 µg/L. Therefore, for the treatability design, iron to Cr6+ ratios of 1,000:1 and 4,000:1 will be evaluated. However, these ratios may be changed based on baseline sampling results. Due to the presence of other constituents in the matrix, it is expected that competition for the electron acceptors will occur, requiring an increased iron amount.

The results of the treatability tests will be used to define the specific amount of ZVI that will be delivered into the subsurface.

3.7 Bore-Hole Installation and Layout

Prior to drilling, each location will be cleared for underground utilities by CH2M-Jones. These utilities will be marked on the pavement surface for easy identification when positioning the drill rig.

To successfully deliver the ZVI powder into the subsurface at SWMU 70, boreholes need to be drilled and stabilized in such a way so that the injection equipment used by ARS can be placed to the desired depths and safely withdrawn when injections are complete. Typically, open boreholes are used throughout the injection procedures. However, based on data for SWMU 70, there is a possibility of borehole collapse. Therefore, a Geoprobe (or similar push-brand) drill rig, capable of driving 4.5-inch outside diameter (OD) casing, will be used to install temporary conduits for the injection equipment.

Using the hydraulic push and hammering capabilities of the Geoprobe (or similar push-brand) drill rig, a 4.5-inch OD threaded heavy wall (HW) casing will be advanced to depth (approximately 28 ft bls). This casing will serve as a conduit for the ARS equipment. Once the packer/nozzle assembly is lowered to depth, the outer drive casing will be raised approximately 3 to 6 ft (depending on the packer configuration) using a hoist truck, thereby exposing the packer and nozzle assembly to the formation. The packers are inflated against the formation using compressed nitrogen, providing a seal above and below the nozzle. Maintaining casing above the packers prevents borehole collapse from burying ARS equipment. The hydraulics on the hoist truck are sufficient to overcome any collapse which may occur around the nozzle assembly before or after injections. Once the injection is complete and the designed dosage of iron powder is emplaced into the formation, the nozzle is raised to the subsequent shallower injection interval, and the entire process is repeated.

Figure 3-2 shows the proposed locations of the Ferox^{SM} injection points at SWMU 70. These 16 injection points were selected on a pattern designed to cover the entire area of the TTA and were based on a 20-ft radius of influence. The locations of these injection points may be adjusted based on analysis of the injection locations by a structural engineer.

3.8 Ferox^{SM} Injection Operations

3.8.1 Pneumatic Fracturing Procedures

The application of the Pneumatic Fracturing injections will be performed using ARS' proprietary process, which relies on a uniquely designed injection system.

The process system consists of a skid-mounted fracture module complete with an injection control manifold and a digital data logger used to monitor various operational parameters. Due to the large quantity of compressed gas needed for fracturing and Ferox^{SM} injections within SWMU 70, ARS will use pressurized nitrogen as the fracturing fluid. A series of bulk nitrogen "tube" trailers will be mobilized to the site for this operation.

The compressed nitrogen is routed through the fracture modules' control manifold and is connected by a high-pressure hose to a proprietary injector. Once the necessary equipment is in place, and all field personnel are instructed on safety aspects of the activities, the outer drive casing will be raised, exposing the injector nozzle to the formation. The packers will be inflated and the formation will be fractured. Fracturing will consist of applying pressurized nitrogen for approximately fifteen seconds within a 20 to 30-inch interval isolated by the use of a double pneumatic straddle packer assembly (the actual injection interval will be finalized in the field).

3.8.2 Pneumatic Fracturing Monitoring Parameters

During each injection, the following system operational parameters will be observed and collected:

- Downhole injection initiation and maintenance pressures
- Injection pressure influence at surrounding monitoring points, if available
- Ground surface heave adjacent to, and in the vicinity of, the injection point

Other visual observations during injection will also be recorded. Detailed discussions of the operational parameters are provided below.

Injection Initiation and Maintenance Pressures

During each injection, a pressure transducer will be used to record data every 1/8 of a second. This data will be used to create a pressure-history curve from which the initiation pressure and the maintenance pressure can be determined. The initiation pressure represents the pressure at which the formation yields to the influx of injection fluids. The maintenance pressure represents the pressure required to maintain the injection flow into the formation. The graphical representation of this data plotted over time provides information as to the in-situ stresses of the formation corresponding to depth, as well as a confirmation that any fractures were created and propagated.

Pressure Influence at Adjacent Wells

During the injections, pressure gauges will be placed at wells near the injection points to monitor for pressure influence. Each pressure gauge is outfitted with a drag arm indicator that records the maximum pressure detected at the monitoring point during the injection. In addition, visual observations will also be used to indicate pressure influence in surrounding wells.

Other injection holes may also serve as monitoring points. In these cases, a packer will be inflated in the top of the open borehole. A pressure gauge, outfitted with a drag arm indicator will be secured to the center rod of the packer assembly in the vacant injection hole. This gauge will record the maximum pressure detected within that borehole during the injection.

Ground Surface Heave Monitoring

Ground surface heave monitoring will be conducted during each injection using surveying transits in conjunction with heave rods. The heave rods will be placed at locations of varying radial distance from the fracture/injection well. During each injection event, the rods will be observed for the maximum amount of upward motion (surface heave) and the post-injection resting position (residual heave). Ground surface heave monitoring data provide additional information that can be used to assess the distances and orientation of injection fluid propagation. Due to the presence of an asphalt surface and building structures, heave is expected to be minimal.

3.9 Ferox^{SM} Injections

Ferox^{SM} injections will be performed immediately following Pneumatic Fracturing at each injection interval within the borehole. The iron powder will be injected into the subsurface utilizing a nitrogen gas stream integrated with a high-pressure, high-flow injection

manifold. The manifold system will provide accurate injection pressures, which will enable ARS to achieve the optimal iron powder dispersion.

The iron slurry-nitrogen mixture will be injected through a proprietary injector and is performed in approximately 20 to 30-inch intervals (the actual injection interval will be finalized in the field) isolated by the use of a pneumatic straddle packer assembly. The duration and number of injections in each borehole are directly dependent upon the quantity of iron desired within the specific zone, which will be calculated based on the treatability study results. Each borehole will be addressed starting at the deepest interval and working upward. This will ensure that borehole stability is maintained. When the targeted dosage of iron is emplaced into the formation, the packers will be deflated, and the nozzle assembly will be raised to the next injection location.

Approximate estimations of the amount of iron powder required have been made based on previous studies involving the reduction of hexavalent chromium with ZVI powder. Once the treatability study is performed on site-specific soil and groundwater from SWMU 70, exact quantities can be calculated. A factor of safety will be included into the iron mass calculation to account for other competing compounds such as trichloroethylene (TCE).

Assuming that each injection has a radial influence of approximately 20 ft, roughly 16 injection boreholes are needed to target the entire area TTA. The location and number of injection points may change depending on presence of utilities and building structures.

The actual injected mass will depend greatly on site-specific limitations such as the extensiveness of inter-connected soil pores and the volume of the iron powder slurry that can be injected into the soils. ARS will attempt to meet and exceed the amount of iron calculated to provide a higher level of assurance in treating the Cr6+ at the site. Due to heterogeneities in the soil, it is possible that areas exist with much higher concentrations of Cr6+. For this reason, ARS will attempt to target the upper limit of the field design as outlined. This will serve as an increased buffer and ensure that the Cr6+ is reduced below target levels.

3.10 Pneumatic Fracturing Effects on Nearby Structures

Structural modeling and analysis of all buildings in the vicinity of the Pneumatic Fracturing operations at SWMU 70 (Buildings 3 and 5) will be conducted to ensure that field operations do not damage integrity of the structures. A key parameter that will be modeled is the maximum tolerable heave of the structure at load bearing points. During Pneumatic Fracturing, surface heave will be monitored (as per section 3.8.2) allowing the field engineer

to monitor whether the maximum tolerable value is being approached. If so, then injection operations can be halted before any damage to the structure can occur.

Based on structural analysis, injection locations may be altered to satisfy safety tolerances.

3.11 Injection Monitoring

During the injection process, ARS personnel will monitor the quantity of slurry injected as well as the duration of injection. The quantity of slurry injected will be recorded after each injection and is measured by either counting the number of "strokes" of the diaphragm pump, or visually measuring the amount of liquid that is displaced from the slurry holding tank. Typically, a single batch of iron powder slurry is mixed and injected at a time, and therefore exact quantities are recorded during each injection.

The injection pressure will also be observed to ensure proper operation of the system and iron powder dispersion into the formation. Personnel will keep record of these and other operational parameters during the field activities. Section 3.8 describes, in detail, the various operational parameters ARS personnel will observe and record during the actual injection process.

3.12 Post-Injection Monitoring

To assess the performance of the technology, CH2M-Jones personnel will conduct post-injection monitoring at SWMU 70. The samples will be collected approximately 30 to 45 calendar days after the injection is complete. Groundwater from the three monitoring wells inside the target treatment area will be analyzed for Cr6+ and Cr(total and dissolved) and MNA parameters (see Table 2-2).

Additionally, five vertical profile locations will be sampled at three different elevations for Cr6+ and Cr(total and dissolved). The post-treatment vertical profile locations will be finalized after the injection is completed and will be approximately evenly distributed across the TTA.

3.13 Reporting

A pilot study report will be provided 30 days after the final performance samples are reported from the laboratory.

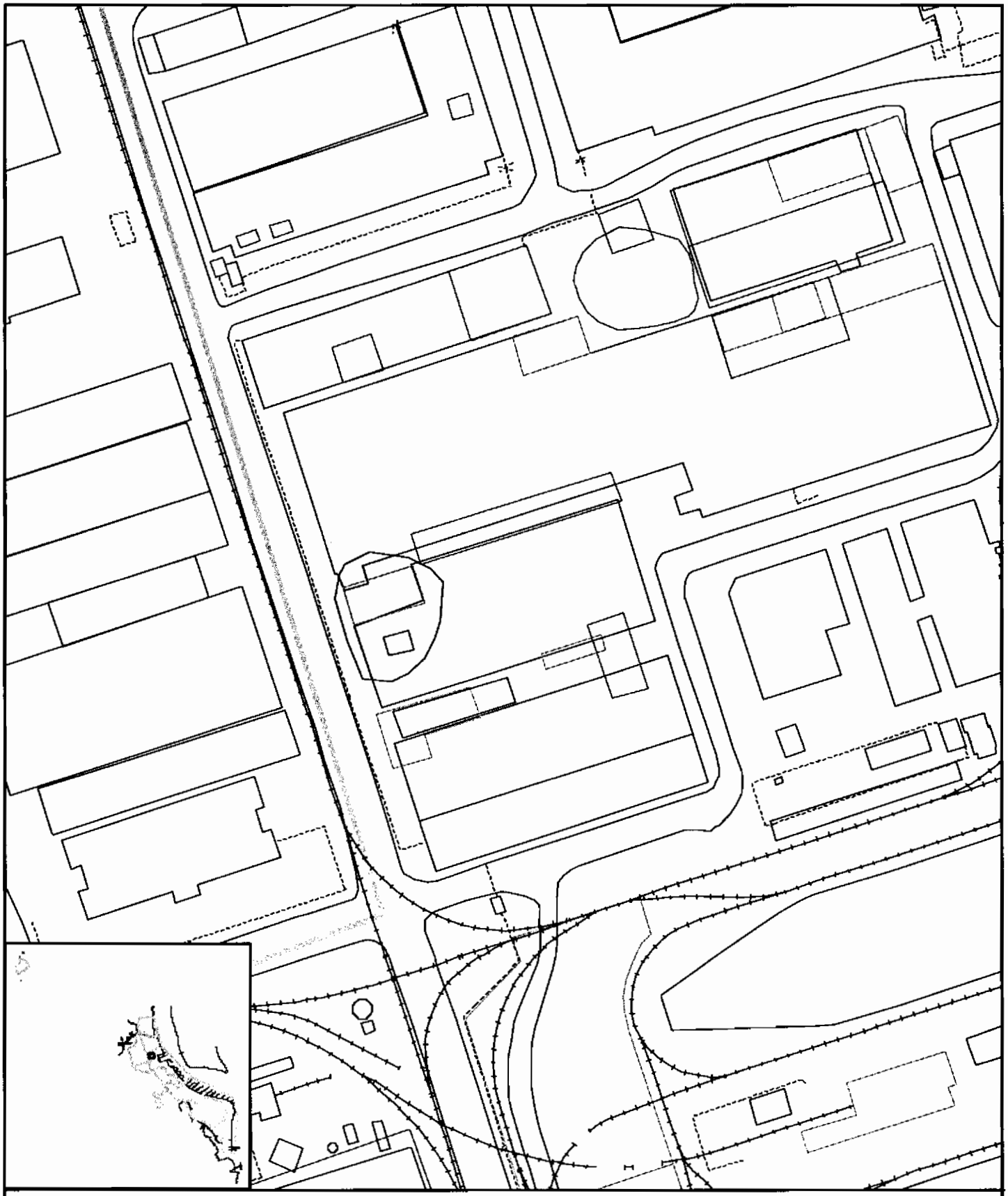
3.14 Permitting

3.14.1 SCDHEC Well Installation Request

In accordance with R.61-79.265 Subpart F of the South Carolina Hazardous Waste Management Regulations, and R.61-71 of the South Carolina Well Standards and Regulations, a request for the advancement of the vertical profiler locations is required to be submitted to SCDHEC two weeks prior to the scheduled activity. The written request provides the purpose of the injection bore-holes and vertical profiler activity and consists of construction details, if required, as well as a map depicting the proposed locations. In addition, because the injection bore-holes and vertical profiler locations are considered temporary, the request will provide the method used for abandonment.

3.14.2 SCDHEC Underground Injection Control Permit Application

An Underground Injection Control Permit will be approved prior to the initiation of field work.



Railroads
Roads
AOC Boundary
SWMU Boundary
Buildings
Zone Boundary
Target Treatment Zone

N

0 100 200 Feet

1 inch = 139.676 feet

Figure 3-1
Target Treatment Area for Pilot Study
SWMU 25-70
Charleston Naval Complex

CH2MHILL

File Path: c:\paulsarcview\aprs\swmu70up.apr, Date: 10 Oct 2001 14:41, User: PFAVARA

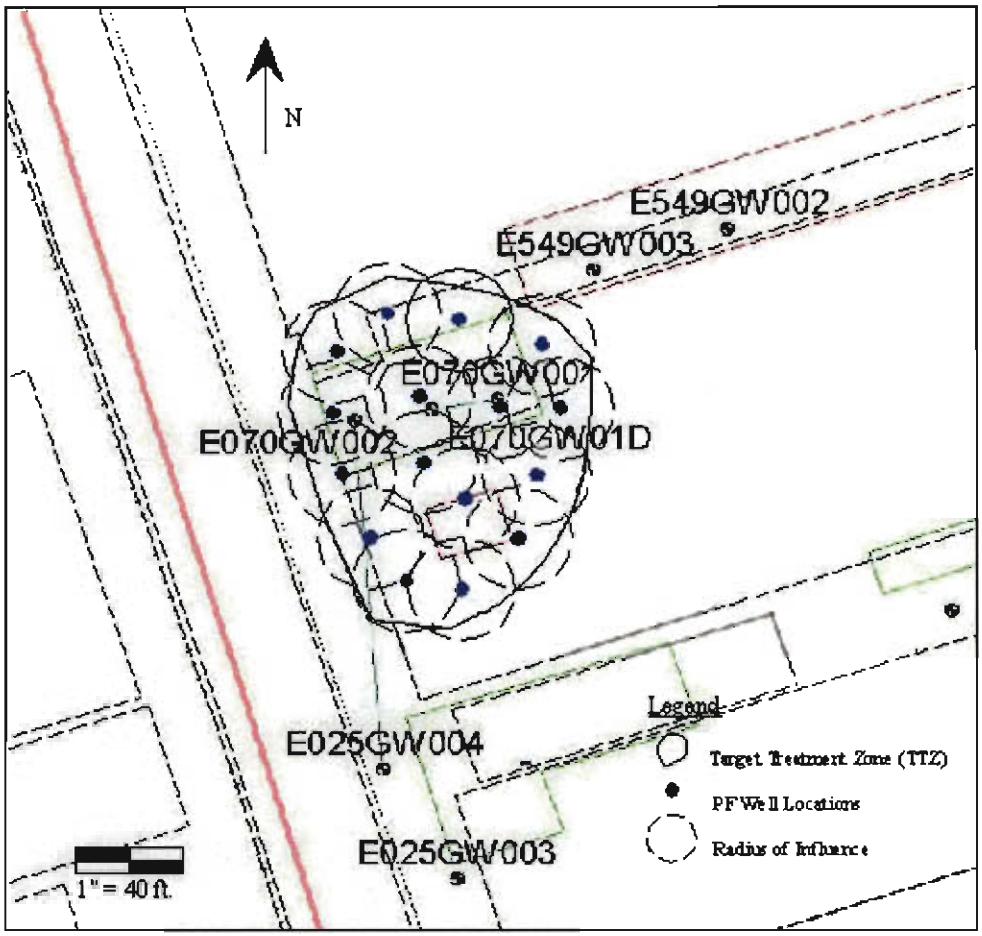


FIGURE 3-2
Proposed Locations of the Ferox[SM] Injection Points
Phase II CMS Work Plan, SWMU 70, Zone E

Section 4.0

4.0 Investigation-Derived Waste

IDW that is generated during this effort will include purge water from the groundwater sampling activities, soil cuttings from injector installation, and personal protective equipment (PPE). IDW will be collected in labeled 55-gallon drums or portable tank for proper handling. Contained IDW will remain on site temporarily until it is transported to the less than 90-day storage facility located at Building 1824. Once the analytical results have been reviewed, the 55-gallon drums or portable tank containing the groundwater contents will be transported, as required, to a permitted and licensed facility for treatment or disposal.

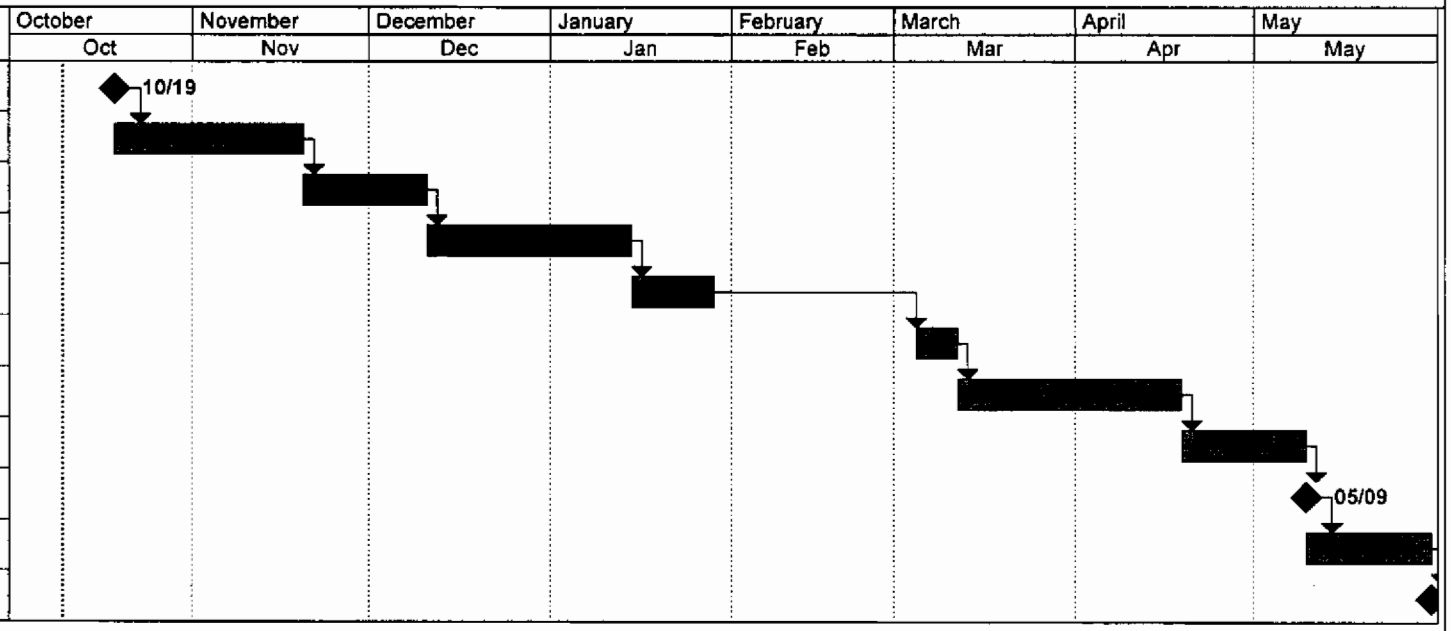
Section 5.0

5.0 Project Schedule

Figure 5-1, shown on the following page, presents the project schedule.

SWMU 70 Pilot Study Schedule
In-Situ Hexavalent Chromium Reduction Using ZVI

ID	Task Name
1	Submit Rev 0 Pilot Study Work Plan
2	SCDHEC Review
3	Comment Resolution
4	Install Injector Casings
5	ZVI Injections
6	Post Treatment Monitoring
7	Labotory Analysis/Data Mgmt
8	Prepare Rev 0 Pilot Study Report
9	Submit Rev 0 Pilot Study Report
10	Comment Resolution
11	Pilot Study Complete



Project: Pilot Study Sked
Date: Wed 10/10/01

Task		Summary		Rolled Up Progress	
Split		Rolled Up Task		External Tasks	
Progress		Rolled Up Split		Project Summary	
Milestone		Rolled Up Milestone			

Page 1

Section 6.0

6.0 References

CH2M-Jones. *Phase I CMS Work Plan– Groundwater Delineation*. Revision 1. December 2000.

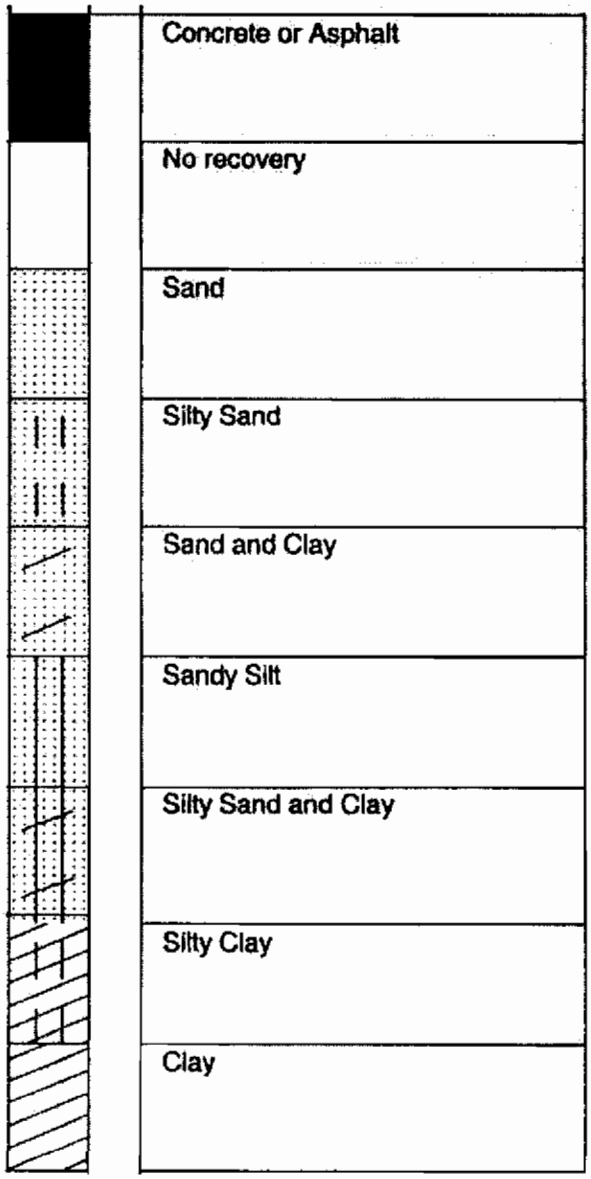
ARS Technologies Inc. and Stevens Institute of Technology. Use of Zero-Valent Iron Powder for the Treatment of Contaminated Dredge Material and Marine Sediments. Zero-Valent Iron Research Grant, New Jersey Commission on Science and Technology. 1998.

ARS Technologies Inc. Interim Progress Report. Submitted to U.S. Army Research Development & Engineering Center/Industrial Ecology. June 2001.

ARS Technologies Inc. Pneumatic Fracturing and Ferox Powder Injections. Interim Report. Submitted to Parsons Engineering Science. October 2001.

Appendix A

Lithology Symbol Legend



SOIL AND BORING COMPLETION LOG

PROJECT NUMBER : 158814

BORING NUMBER : E070GP002
SHEET 1 of 2

PROJECT : Charleston Naval Complex
DRILLING METHOD : GeoProbe
DRILLING CONTRACTOR : Columbia
START : April 4, 2001
FINISH : April 4, 2001
LOGGER : T. Beisel

NORTHING (ft) : 376554.1905
EASTING (ft) : 2316624.3022
LOCATION : SWMU 25/70
GROUND SURFACE ELEVATION (ft msl) : 9.0332
WATER LEVEL AND DATE (ft bgs) : Approx. 7 feet

DEPTH BELOW SURFACE (FT)	WATER LEVEL	SAMPLE NUMBER	SAMPLE RECOVERY	STANDARD PENETRATION 6"-6"-6" (N)	SAMPLE RECOVERY	SYMBOL	USCS SYMBOL	SAMPLE DESCRIPTION	COMMENTS
								Asphalt	
1								Dense grey silty fine SAND, dry	
2		1	75	na	75			Compact mottled reddish brown to tan silty fine SAND, dry	
3								No recovery	
4								Compact tan fine SAND, damp	
5									
6		2	100	na	100			Compact tan silty SAND, wet at approximately 7 feet	
7									
8								Compact light brown to tan silty fine SAND, wet	
9									
10		3	100	na	100				
11									
12								Tan compact silty fine SAND, wet	
13									
14		4	100	na	100				
15								Reddish brown compact silty fine SAND, wet	
16								Compact reddish brown silty fine SAND, interbedded with 1" medium plastic CLAY, wet	
17									
18		5	100	na	100				
19									
20								Loose reddish brown silty fine SAND, wet	
21									
22		6	100	na	100				
23								Dark tan fine to medium well sorted SAND, wet	
24								Ashley Formation Dense dark olive grey silty low plasticity CLAY, trace fine to medium sand, wet	
25									

SOIL AND BORING COMPLETION LOG

PROJECT NUMBER : 158814

BORING NUMBER : E070GP002

PROJECT : Charleston Naval Complex
DRILLING METHOD : GeoProbe
DRILLING CONTRACTOR : Columbia
START : April 4, 2001
FINISH : April 4, 2001
LOGGER : T. Belsel

NORTHING (ft) : 376554.1905
EASTING (ft) : 2316624.3022
LOCATION : SWMU 25/70
GROUND SURFACE ELEVATION (ft msl) : 9.0332
WATER LEVEL AND DATE (ft bgs) : Approx. 7 feet

DEPTH BELOW SURFACE (FT)	WATER LEVEL	SAMPLE NUMBER	SAMPLE RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	RECOVERY	SYMBOL	USCS SYMBOL	SAMPLE DESCRIPTION	COMMENTS
26		7	100	na	100			Ashley Formation Dense dark olive grey silty low plasticity CLAY, trace fine to medium sand, wet	
27								Ashley Formation Stiff dark olive grey CLAY interbedded with loose 2" to 3" stringers of olive grey silty fine to medium sand and shell	
28									
29									
30									
31									
32									
33									
34									
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50									

SOIL AND BORING COMPLETION LOG

PROJECT NUMBER : 158814

BORING NUMBER : E070GP003
SHEET 1 of 2

PROJECT : Charleston Naval Complex
DRILLING METHOD : GeoProbe
DRILLING CONTRACTOR : Columbia
START : April 4, 2001
FINISH : April 4, 2001
LOGGER : T. Beisel

NORTHING (ft) : 376496.4541
EASTING (ft) : 2316501.9454
LOCATION : SWMU 25/70
GROUND SURFACE ELEVATION (ft msl) : 10.0366
WATER LEVEL AND DATE (ft bgs) : Approx. 7 feet

DEPTH BELOW SURFACE (FT)	WATER LEVEL	SAMPLE NUMBER	SAMPLE RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	SAMPLE RECOVERY	SYMBOL	USCS SYMBOL	SAMPLE DESCRIPTION	COMMENTS
1, 2, 3, 4		1	50	na	50			Dense organic rich grey sandy SILT, dry (top soil) Dense mottled reddish brown to tan silty fine SAND, dry no recovery	
4, 5, 6, 7, 8		2	100	na	100			Dense mottled brownish orange sandy silt, damp Dense tan silty fine SAND, wet at approx. 7 feet	
8, 9, 10, 11, 12		3	100	na	100			Very loose tan fine to medium well sorted SAND, wet Dense well sorted fine to medium silty SAND, wet	
12, 13, 14, 15, 16		4	100	na	100			Compact tan silty fine SAND, wet Compact well sorted silty fine to medium SAND, wet	
16, 17, 18, 19, 20		5	100	na	100			Compact mottled reddish brown to tan silty fine SAND, wet Compact tan silty fine to medium well sorted SAND, wet	
20, 21, 22, 23, 24, 25		6	100	na	100			Compact tan silty fine to medium well sorted SAND, wet Ashley Formation Grades into dense dark olive grey silty fine to medium SAND AND SHELL, interbedded with stiff dark olive grey clay	

SOIL AND BORING COMPLETION LOG

PROJECT NUMBER : 158814

BORING NUMBER : E070GP003

SHEET 2 of 2

PROJECT : Charleston Naval Complex
DRILLING METHOD : GeoProbe
DRILLING CONTRACTOR : Columbia
START : April 4, 2001
FINISH : April 4, 2001
LOGGER : T. Beisel

NORTHING (ft) : 376496.4541
EASTING (ft) : 2316501.9454
LOCATION : SWMU 25/70
GROUND SURFACE ELEVATION (ft msl) : 10.0366
WATER LEVEL AND DATE (ft bgs) : Approx. 7 feet

DEPTH BELOW SURFACE (FT)	WATER LEVEL	SAMPLE NUMBER	SAMPLE RECOVERY	STANDARD PENETRATION 6"-6"-6" (N)	SAMPLE RECOVERY	SAMPLE SYMBOL	USCS SYMBOL	SAMPLE DESCRIPTION	COMMENTS
26		7	100	na	100			**Ashley Formation** Dense dark olive grey silty low plasticity CLAY, trace fine to medium sand, interbedded with 2" to 3" dark olive grey well sorted fine to medium sand	
27									
28									
29									
30									
31									
32									
33									
34									
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50									

SOIL AND BORING COMPLETION LOG

PROJECT NUMBER : 158814

BORING NUMBER : E070GP007
SHEET 1 of 1

PROJECT : SWMU 25/70
DRILLING METHOD : GeoProbe Acetate Sleeve
DRILLING CONTRACTOR : Columbia
START : April 4, 2001
FINISH : April 4, 2001
LOGGER : T. Beisel

NORTHING (ft) : 376554.1905
EASTING (ft) : 2316624.3022
LOCATION : SMWU 25/70
GROUND SURFACE ELEVATION (ft msl) : 9.0332
WATER LEVEL AND DATE (ft bgs) : approx 7 feet

DEPTH BELOW SURFACE (FT)	WATER LEVEL	SAMPLE NUMBER	SAMPLE RECOVERY	STANDARD PENETRATION 6"-6"-6" (N)	SAMPLE RECOVERY	SYMBOL	USCS SYMBOL	SAMPLE DESCRIPTION	COMMENTS
1–3		1	50	na	50			Asphalt Dense grey silty fine SAND, dry Compact brownish tan silty fine SAND, dry No recovery	
4–8		2	75	na	75			Loose tan silty fine SAND, grades to silty medium SAND, wet at approximatly 7 feet	
9–12		3	100	na	100			Loose tan silty fine SAND, wet Compact mottled tan to reddish brown silty fine SAND, wet	
13–16		4	100	na	100			Compact tan silty fine SAND, wet Tan moderatly plastic CLAY, wet Tan slightly plastic sandy CLAY, wet	
17–20		5	100	na	100			Dense mottled tan to reddish brown silty fine SAND, wet Mottled tan to reddish brown sandy CLAY, interbedded with 2" stiff clay lenses, wet	
21–24		6	100	na	100			Compact tan silty fine SAND, wet Mottled compact tan to dark red silty fine to medium SAND with 1" to 2" interbedded stiff CLAY stringers, wet	
25								Ashley Formation Dense dark olive silty CLAY, wet	

SOIL AND BORING COMPLETION LOG

PROJECT NUMBER : 158814

BORING NUMBER : E070GP009

SHEET 1 of 2

PROJECT : Charleston Naval Complex
DRILLING METHOD : GeoProbe
DRILLING CONTRACTOR : Columbia
START : April 3, 2001
FINISH : April 3, 2001
LOGGER : T. Belsel

NORTHING (ft) : 376684.4091
EASTING (ft) : 2316573.4171
LOCATION : SWMU 25/70
GROUND SURFACE ELEVATION (ft msl) : 8.8153
WATER LEVEL AND DATE (ft bgs) : not measured

DEPTH BELOW SURFACE (FT)	WATER LEVEL	SAMPLE NUMBER	SAMPLE RECOVERY	STANDARD PENETRATION 6"-6"-6"- (N)	SAMPLE RECOVERY	SYMBOL	USCS SYMBOL	SAMPLE DESCRIPTION	COMMENTS
								Concrete	
1								Compact brownish tan silty fine SAND, dry	
2		1	50	na	50			No recovery	
3									
4								Compact reddish brown sandy SILT, damp	
5								Compact reddish brown sandy SILT interbedded with brownish tan silty fine SAND, wet	
6		2	75	na	75				
7								No recovery	
8								Compact silty fine SAND interbedded with reddish brown silty fine SAND, wet	
9									
10		3	100	na	100			Compact tan silty fine SAND, wet	
11									
12								Compact tan silty fine SAND, wet	
13									
14		4	100	na	100				
15									
16								Compact tan fine SAND, wet	
17									
18		5	100	na	100				
19									

SOIL AND BORING COMPLETION LOG

PROJECT NUMBER : 158814

BORING NUMBER : E070GP009

PROJECT : Charleston Naval Complex
DRILLING METHOD : GeoProbe
DRILLING CONTRACTOR : Columbia
START : April 3, 2001
FINISH : April 3, 2001
LOGGER : T. Beisel

NORTHING (ft) : 376684.4091
EASTING (ft) : 2316573.4171
LOCATION : SWMU 25/70
GROUND SURFACE ELEVATION (ft msl) : 8.8153
WATER LEVEL AND DATE (ft bgs) : not measured

DEPTH BELOW SURFACE (FT)	WATER LEVEL	SAMPLE NUMBER	SAMPLE RECOVERY	STANDARD PENETRATION 6"-6"-6" (N)	SAMPLE RECOVERY	SAMPLE SYMBOL	USCS SYMBOL	SAMPLE DESCRIPTION	COMMENTS
20								Compact reddish brown silty fine SAND interbedded with 1" to 2" medium plastic grey CLAY stringers at 19.5 to 20 feet	
21								Very loose light tan fine SAND, wet, "flowing sand"	
22		6	50	na	50				
23									
24								Compact dark tan fine SAND, wet	
								Very loose tan fine SAND, likely caved in from above, wet	
25								Dense mottled reddish brown to tan silty fine SAND with 2" to 3" medium plastic grey CLAY stringers, wet	
26		7	100	na	100				
27									
28								Dense mottled reddish brown to tan fine SAND with 1" to 2" grey CLAY stringers, wet	
29									
30		8	100	na	100				
31									
32								Dense mottled reddish brown to tan silty fine SAND, wet	
33									
34		9	100	na	100				
35								Ashley Formation Dense dark olive silty medium SAND with 2" to 3" clay stringers, wet	
36									
37									
38									

Appendix B

Analytical Data Summary

	StationID	E025GW001		E025GW002		E025GW003		E025GW003	
	SampleID	025GW001L1		025GW002L1		025GW003L1		025HW003L1	
	DateCollected	04/06/2001 0:00		04/06/2001 0:00		04/06/2001 0:00		04/06/2001 0:00	
	DateAnalyzed	04/12/2001		04/12/2001		04/12/2001		04/12/2001	
	SDGNumber	40369		40369		40369		40369	
Parameter	**Units**								
Cadmium, Dissolved	ug/L	0.272	U	4.58	J	72.7	=	74	=
Chromium (Hexavalent), Dissolved	ug/L								
Chromium, Dissolved	ug/L	23.4	=	128	=	2380	=	2420	=
Manganese, Dissolved	ug/L	6.41	J	6.21	J	274	=	277	=
Iron, Dissolved	ug/L	3.27	U	3.27	U	3.27	U	3.27	U

	StationID	E025GW004		E070GW001		E070GW002		E070GW01D	
	SampleID	025GW004L1		070GW001L1		070GW002L1		070GW01DL1	
	DateCollected	04/06/2001 0:00		04/05/2001 0:00		04/05/2001 0:00		04/05/2001 0:00	
	DateAnalyzed	04/12/2001		04/12/2001		04/12/2001		04/12/2001	
	SDGNumber	40369		40369		40369		40369	
Parameter	**Units**								
Cadmium, Dissolved	ug/L	0.757	U	0.639	U	1.01	U	2.28	J
Chromium (Hexavalent), Dissolved	ug/L								
Chromium, Dissolved	ug/L	3.97	U	2070	=	19.8	=	30600	=
Manganese, Dissolved	ug/L	0.338	U	1.18	J	48.3	=	192	=
Iron, Dissolved	ug/L	3.27	U	5.66	U	3.27	U	3.27	U

	StationID	E070VP001		E070VP001		E070VP001		E070VP002	
	SampleID	070VP00109		070VP00120		070VP00130		070HP00209	
	DateCollected	04/06/2001 0:00		04/06/2001 0:00		04/06/2001 0:00		03/05/2001 0:00	
	DateAnalyzed	04/12/2001		04/12/2001		04/12/2001		04/12/2001	
	SDGNumber	40367		40367		40367		40284	
Parameter	**Units**								
Cadmium, Dissolved	ug/L	0.272	U	0.272	U	0.272	U	0.272	U
Chromium (Hexavalent), Dissolved	ug/L								
Chromium, Dissolved	ug/L	0.582	U	0.582	U	0.582	U	0.582	UJ
Manganese, Dissolved	ug/L	44.1	=	14.9	U	252	=	11.5	J
Iron, Dissolved	ug/L	6.02	U	10.6	U	3.27	U	3.27	U

	StationID	E070VP002		E070VP002		E070VP002		E070VP003	
	SampleID	070VP00209		070VP00215		070VP00220		070VP00309	
	DateCollected	03/05/2001 0:00		03/05/2001 0:00		03/05/2001 0:00		04/06/2001 0:00	
	DateAnalyzed	04/12/2001		04/12/2001		04/12/2001		04/12/2001	
	SDGNumber	40284		40284		40284		40367	
Parameter	**Units**								
Cadmium, Dissolved	ug/L	0.272	U	0.272	U	0.272	U	0.272	U
Chromium (Hexavalent), Dissolved	ug/L								
Chromium, Dissolved	ug/L	0.582	UJ	19.5	J	287	J	73.2	=
Manganese, Dissolved	ug/L	9.16	J	17.8	=	60.2	=	4.62	U
Iron, Dissolved	ug/L	4.33	U	9.27	U	3.27	U	3.27	U

	StationID	E070VP003		E070VP003		E070VP004		E070VP004	
	SampleID	070VP00315		070VP00320		070VP00409		070VP00415	
	DateCollected	04/06/2001 0:00		04/06/2001 0:00		04/06/2001 0:00		04/06/2001 0:00	
	DateAnalyzed	04/12/2001		04/12/2001		04/12/2001		04/12/2001	
	SDGNumber	40367		40367		40367		40367	
Parameter	**Units**								
Cadmium, Dissolved	ug/L	0.506	U	0.272	U	0.272	U	0.272	U
Chromium (Hexavalent), Dissolved	ug/L								
Chromium, Dissolved	ug/L	852	=	0.582	U	0.922	U	0.582	U
Manganese, Dissolved	ug/L	33.6	=	115	=	0.68	U	248	=
Iron, Dissolved	ug/L	3.27	U	3.27	U	11.2	U	3.27	U

	StationID	E070VP004		E070VP005		E070VP005		E070VP005	
	SampleID	070VP00420		070VP00509		070VP00515		070VP00520	
	DateCollected	04/06/2001 0:00		04/06/2001 0:00		04/06/2001 0:00		04/09/2001 0:00	
	DateAnalyzed	04/12/2001		04/12/2001		04/12/2001		04/10/2001	
	SDGNumber	40367		40367		40367		40464	
Parameter	**Units**								
Cadmium, Dissolved	ug/L	0.272	U	0.272	U	0.272	U		
Chromium (Hexavalent), Dissolved	ug/L							0.00001	UJ
Chromium, Dissolved	ug/L	0.582	U	0.582	U	0.582	U		
Manganese, Dissolved	ug/L	172	=	39.3	=	665	=		
Iron, Dissolved	ug/L	3.27	U	9.38	U	125	=		

	StationID	E070VP005		E070VP008		E070VP008		E070VP008	
	SampleID	070VP00520		070VP00809		070VP00820		070VP00828	
	DateCollected	04/09/2001 0:00		03/05/2001 0:00		03/05/2001 0:00		03/05/2001 0:00	
	DateAnalyzed	04/13/2001		04/12/2001		04/12/2001		04/12/2001	
	SDGNumber	40464		40284		40284		40284	
Parameter	**Units**								
Cadmium, Dissolved	ug/L	0.272	U	2.49	J	20.7	=	0.272	U
Chromium (Hexavalent), Dissolved	ug/L								
Chromium, Dissolved	ug/L	0.582	U	1690	J	9010	J	3220	J
Manganese, Dissolved	ug/L	414	=						
Iron, Dissolved	ug/L	3.27	U						

	StationID	E070VP011		E070VP011		E070VP011		E070VP012	
	SampleID	070VP01109		070VP01119		070VP01133		070VP01209	
	DateCollected	04/12/2001 0:00		04/12/2001 0:00		04/12/2001 0:00		03/05/2001 0:00	
	DateAnalyzed	04/18/2001		04/18/2001		04/18/2001		04/12/2001	
	SDGNumber	40694		40694		40694		40284	
Parameter	**Units**								
Cadmium, Dissolved	ug/L	0.272	U	0.272	U	0.272	U	0.272	U
Chromium (Hexavalent), Dissolved	ug/L								
Chromium, Dissolved	ug/L	0.582	U	0.582	U	0.582	U	0.582	UJ
Manganese, Dissolved	ug/L	116	=	34.5	=	70.4	=	145	=
Iron, Dissolved	ug/L	3.27	U	1310	J	3.27	U	3.27	U

	StationID	E070VP012		E070VP012		E549GW00	E549G		E549GW003	
	SampleID	070VP01220		070VP01230		549GW001	549GW		549GW003L1	
	DateCollected	03/05/2001 0:00		03/05/2001 0:00		04/05/2001 0:00			04/06/2001 0:00	
	DateAnalyzed	04/12/2001		04/12/2001		04/12/2001			04/12/2001	
	SDGNumber	40284		40284		40369	40		40369	
Parameter	**Units**									
Cadmium, Dissolved	ug/L	0.272	U	0.272	U	0.413	U		0.433	U
Chromium (Hexavalent), Dissolved	ug/L									
Chromium, Dissolved	ug/L	765	J	0.582	UJ	0.582	U		30.2	=
Manganese, Dissolved	ug/L	141	=	149	=	1.14	J		0.338	U
Iron, Dissolved	ug/L	3.27	U	3.27	U	7.2	U		3.27	U

	StationID	E025GW001		E025GW002		E025GW003		E025GW003		E025GW003	
	SampleID	025GW001L1		025GW002L1		025GW003L1		025GW003L1		025HW003L1	
	DateCollected	04/06/2001 0:00		04/06/2001 0:00		04/06/2001 0:00		04/06/2001 0:00		04/06/2001 0:00	
	DateAnalyzed	04/07/2001		04/07/2001		04/07/2001		04/27/2001		04/07/2001	
	SDGNumber	40369		40369		40369		40369		40369	
Parameter	**Units**										
Chromium (Hexavalent)	ug/L	0.000033	UJ	0.000147	=			0.00291	J		
Nitrate-Nitrite-N	ug/L					0.00005	U			0.00005	U
Sulfate (as SO4)	ug/L					0.0396	=			0.0395	=

	StationID	E025GW003		E025GW004		E070GW001		E070GW001		E070GW002	
	SampleID	025HW003L1		025GW004L1		070GW001L1		070GW001L1		070GW002L1	
	DateCollected	04/06/2001 0:00		04/06/2001 0:00		04/05/2001 0:00		04/05/2001 0:00		04/05/2001 0:00	
	DateAnalyzed	04/27/2001		04/07/2001		04/07/2001		04/27/2001		04/07/2001	
	SDGNumber	40369		40369		40369		40369		40369	
Parameter	**Units**										
Chromium (Hexavalent)	ug/L	0.00272	J	0.000023	U			0.00258	J	0.00004	UJ
Nitrate-Nitrite-N	ug/L					0.00808	=				
Sulfate (as SO4)	ug/L					0.0137	=				

	StationID	E070GW01D	E070GW01D	E070VP001	E070VP001	E070VP001
	SampleID	070GW01DL1	070GW01DL1	070VP00109	070VP00120	070VP00130
	DateCollected	04/05/2001 0:00	04/05/2001 0:00	04/06/2001 0:00	04/06/2001 0:00	04/06/2001 0:00
	DateAnalyzed	04/07/2001	04/27/2001	04/06/2001	04/06/2001	04/06/2001
	SDGNumber	40369	40369	40367	40367	40367
Parameter	**Units**					
Chromium (Hexavalent)	ug/L		0.031 J	0.000015 =	0.0000197 =	0.000013 =
Nitrate-Nitrite-N	ug/L	0.00005 U				
Sulfate (as SO4)	ug/L	0.181 =				

	StationID	E070VP001		E070VP002		E070VP002		E070VP002		E070VP002	
	SampleID	070VP001L1		070HP00209		070VP00209		070VP00215		070VP00220	
	DateCollected	04/06/2001 0:00		03/05/2001 0:00		03/05/2001 0:00		03/05/2001 0:00		03/05/2001 0:00	
	DateAnalyzed	04/06/2001		04/06/2001		04/06/2001		04/06/2001		04/06/2001	
	SDGNumber	40367		40284		40284		40284		40284	
Parameter	**Units**										
Chromium (Hexavalent)	ug/L	0.00001	U	0.00001	UJ	0.00001	UJ	0.000024	J	0.00066	J
Nitrate-Nitrite-N	ug/L										
Sulfate (as SO4)	ug/L										

	StationID	E070VP003	E070VP003	E070VP003	E070VP004	E070VP004
	SampleID	070VP00309	070VP00315	070VP00320	070VP00409	070VP00415
	DateCollected	04/06/2001 0:00	04/06/2001 0:00	04/06/2001 0:00	04/06/2001 0:00	04/06/2001 0:00
	DateAnalyzed	04/06/2001	04/27/2001	04/06/2001	04/06/2001	04/06/2001
	SDGNumber	40367	40367	40367	40367	40367
Parameter	**Units**					
Chromium (Hexavalent)	ug/L	0.000161 =	0.000917 J	0.000021 =	0.000017 =	0.000019 =
Nitrate-Nitrite-N	ug/L					
Sulfate (as SO4)	ug/L					

	StationID	E070VP004	E070VP005	E070VP005	E070VP006	E070VP006
	SampleID	070VP00420	070VP00509	070VP00515	0704VP00609	070VP00617
	DateCollected	04/06/2001 0:00	04/06/2001 0:00	04/06/2001 0:00	04/09/2001 0:00	04/09/2001 0:00
	DateAnalyzed	04/06/2001	04/06/2001	04/06/2001	04/10/2001	04/10/2001
	SDGNumber	40367	40367	40367	40464	40464
Parameter	**Units**					
Chromium (Hexavalent)	ug/L	0.000013 =	0.000012 =	0.000006 J	0.0000066 J	0.00001 UJ
Nitrate-Nitrite-N	ug/L					
Sulfate (as SO4)	ug/L					

	StationID	E070VP006		E070VP006		E070VP007		E070VP007		E070VP007	
	SampleID	07OHP0617		07VP00625		07OVP00709		07OVP00716		07OVP00722	
	DateCollected	04/09/2001 0:00		04/09/2001 0:00		04/10/2001 0:00		04/10/2001 0:00		04/10/2001 0:00	
	DateAnalyzed	04/10/2001		04/10/2001		04/27/2001		04/27/2001		04/27/2001	
	SDGNumber	40464		40464		40516		40516		40516	
Parameter	**Units**										
Chromium (Hexavalent)	ug/L	0.00001	UJ	0.00001	UJ	0.000391	J	0.000371	J	0.00001	UJ
Nitrate-Nitrite-N	ug/L										
Sulfate (as SO4)	ug/L										

	StationID	E070VP008		E070VP008		E070VP008		E070VP009		E070VP009	
	SampleID	070VP00809		070VP00820		070VP00828		07OVP00909		07OVP00919	
	DateCollected	03/05/2001 0:00		03/05/2001 0:00		03/05/2001 0:00		04/10/2001 0:00		04/10/2001 0:00	
	DateAnalyzed	04/06/2001		04/06/2001		04/06/2001		04/10/2001		04/10/2001	
	SDGNumber	40284		40284		40284		40516		40516	
Parameter	**Units**										
Chromium (Hexavalent)	ug/L	0.00162	J	0.0094	J	0.00368	J	0.000148	U	0.00086	=
Nitrate-Nitrite-N	ug/L										
Sulfate (as SO4)	ug/L										

	StationID	E070VP009		E070VP010		E070VP010		E070VP010	
	SampleID	07OVP00933		07OVP01009		07OVP01019		07OVP01033	
	DateCollected	04/10/2001 0:00		04/10/2001 0:00		04/10/2001 0:00		04/10/2001 0:00	
	DateAnalyzed	04/27/2001		04/10/2001		04/10/2001		04/10/2001	
	SDGNumber	40516		40516		40516		40516	
Parameter	**Units**								
Chromium (Hexavalent)	ug/L	0.00001	UJ	0.000023	U	0.000199	U	0.000041	U
Nitrate-Nitrite-N	ug/L								
Sulfate (as SO4)	ug/L								

	StationID	E070VP011		E070VP011		E070VP011		E070VP012	
	SampleID	070VP01109		070VP01119		070VP01133		070VP01209	
	DateCollected	04/12/2001 0:00		04/12/2001 0:00		04/12/2001 0:00		03/05/2001 0:00	
	DateAnalyzed	04/13/2001		04/13/2001		04/13/2001		04/06/2001	
	SDGNumber	40694		40694		40694		40284	
Parameter	**Units**								
Chromium (Hexavalent)	ug/L	0.00005	U	0.00001	U	0.00001	U	0.00002	J
Nitrate-Nitrite-N	ug/L								
Sulfate (as SO4)	ug/L								

	StationID	E070VP012		E070VP012		E070VP013		E070VP013	
	SampleID	070VP01220		070VP01230		07OVP01309		07OVP01316	
	DateCollected	03/05/2001 0:00		03/05/2001 0:00		04/10/2001 0:00		04/10/2001 0:00	
	DateAnalyzed	04/06/2001		04/06/2001		04/10/2001		04/10/2001	
	SDGNumber	40284		40284		40516		40516	
Parameter	**Units**								
Chromium (Hexavalent)	ug/L	0.0008	J	0.00001	UJ	0.000035	U	0.00006	U
Nitrate-Nitrite-N	ug/L								
Sulfate (as SO4)	ug/L								

	StationID	E070VP013		E070VP014		E070VP014		E070VP015	
	SampleID	07OVP01322		070VP01409		070VP01422		070VP01509	
	DateCollected	04/10/2001 0:00		04/09/2001 0:00		04/09/2001 0:00		04/09/2001 0:00	
	DateAnalyzed	04/27/2001		04/10/2001		04/10/2001		04/10/2001	
	SDGNumber	40516		40464		40464		40464	
Parameter	**Units**								
Chromium (Hexavalent)	ug/L	0.00001	UJ	0.00001	UJ	0.0000183	=	0.00001	U
Nitrate-Nitrite-N	ug/L								
Sulfate (as SO4)	ug/L								

	StationID	E070VP015		E070VP015		E549GW001		E549GW002		E549GW002	
	SampleID	070VP01516		070VP01522		549GW001L1		549GW002L1		549GW002L1	
	DateCollected	04/09/2001 0:00		04/09/2001 0:00		04/05/2001 0:00		04/06/2001 0:00		04/06/2001 0:00	
	DateAnalyzed	04/10/2001		04/10/2001		04/07/2001		04/07/2001		04/07/2001	
	SDGNumber	40464		40464		40369		40369		40369	
Parameter	**Units**										
Chromium (Hexavalent)	ug/L	0.00001	U	0.00001	U	0.000024	UJ			0.000044	UJ
Nitrate-Nitrite-N	ug/L							0.000979	=		
Sulfate (as SO4)	ug/L							0.0317	=		

	StationID	E549GW003		E549GW003	
	SampleID	549GW003L1		549GW003L1	
	DateCollected	04/06/2001 0:00		04/06/2001 0:00	
	DateAnalyzed	04/07/2001		04/07/2001	
	SDGNumber	40369		40369	
Parameter	**Units**				
Chromium (Hexavalent)	ug/L			0.000047	UJ
Nitrate-Nitrite-N	ug/L	0.00475	=		
Sulfate (as SO4)	ug/L	0.039	=		

	StationID	E070VP006		E070VP006		E070VP006		E070VP006		E070VP007	
	SampleID	0704VP00609		070VP00617		07OHP0617		07VP00625		07OVP00709	
	DateCollected	04/09/2001 0:00		04/09/2001 0:00		04/09/2001 0:00		04/09/2001 0:00		04/10/2001 0:00	
	DateAnalyzed	04/13/2001		04/13/2001		04/13/2001		04/13/2001		04/13/2001	
	SDGNumber	40464		40464		40464		40464		40516	
Parameter	**Units**										
Cadmium	ug/L	0.272	U	0.34	J	0.412	J	0.272	U	127	=
Chromium, Total	ug/L	4.77	J	0.582	U	0.582	U	0.582	U	434	=
Iron	ug/L	30	U	3.27	U	4.94	U	3.27	U	33.6	J
Manganese	ug/L	26.8	=	1650	=	1450	=	292	=	139	=

	StationID	E070VP007		E070VP007		E070VP009		E070VP009		E070VP009	
	SampleID	07OVP00716		07OVP00722		07OVP00909		07OVP00919		07OVP00933	
	DateCollected	04/10/2001 0:00		04/10/2001 0:00		04/10/2001 0:00		04/10/2001 0:00		04/10/2001 0:00	
	DateAnalyzed	04/13/2001		04/13/2001		04/13/2001		04/13/2001		04/13/2001	
	SDGNumber	40516		40516		40516		40516		40516	
Parameter	**Units**										
Cadmium	ug/L	11.5	=	0.547	J	0.621	J	0.937	J	0.272	U
Chromium, Total	ug/L	361	=	0.711	U	0.582	U	43200	=	5.63	U
Iron	ug/L	13.2	U	3.27	U	3.27	U	3.27	U	3.27	U
Manganese	ug/L	95	=	159	=	9.87	J	150	=	264	=

	StationID	E070VP010		E070VP010		E070VP010		E070VP013		E070VP013	
	SampleID	07OVP01009		07OVP01019		07OVP01033		07OVP01309		07OVP01316	
	DateCollected	04/10/2001 0:00		04/10/2001 0:00		04/10/2001 0:00		04/10/2001 0:00		04/10/2001 0:00	
	DateAnalyzed	04/13/2001		04/13/2001		04/13/2001		04/13/2001		04/13/2001	
	SDGNumber	40516		40516		40516		40516		40516	
Parameter	**Units**										
Cadmium	ug/L	0.272	U	0.737	J	0.272	U	71.4	=	50.5	=
Chromium, Total	ug/L	1.23	U	44600	=	6.49	U	602	=	71.2	=
Iron	ug/L	11.7	U	3.27	U	3.27	U	323	=	379	=
Manganese	ug/L	5.66	J	147	=	262	=	32.2	=	103	=

	StationID	E070VP013		E070VP014		E070VP014		E070VP015		E070VP015	
	SampleID	07OVP01322		070VP01409		070VP01422		070VP01509		070VP01516	
	DateCollected	04/10/2001 0:00		04/09/2001 0:00		04/09/2001 0:00		04/09/2001 0:00		04/09/2001 0:00	
	DateAnalyzed	04/13/2001		04/13/2001		04/13/2001		04/13/2001		04/13/2001	
	SDGNumber	40516		40464		40464		40464		40464	
Parameter	**Units**										
Cadmium	ug/L	0.272	U	0.272	U	0.272	U	7.81	=	0.272	U
Chromium, Total	ug/L	0.582	U	0.582	U	0.582	U	0.993	U	19.7	=
Iron	ug/L	213	=	5.02	U	3.27	U	3.78	U	150	=
Manganese	ug/L	104	=	10.7	J	73.6	=	17.8	=	59.7	=

	StationID	E070VP015	
	SampleID	070VP01522	
	DateCollected	04/09/2001 0:00	
	DateAnalyzed	04/13/2001	
	SDGNumber	40464	
Parameter	**Units**		
Cadmium	ug/L	0.272	U
Chromium, Total	ug/L	0.582	U
Iron	ug/L	476	=
Manganese	ug/L	500	=

	StationID	E025GW003		E025GW003		E070GW001		E070GW01D		E549GW002	
	SampleID	025GW003L1		025HW003L1		070GW001L1		070GW01DL1		549GW002L1	
	DateCollected	04/06/2001 0:00		04/06/2001 0:00		04/05/2001 0:00		04/05/2001 0:00		04/06/2001 0:00	
	DateAnalyzed	04/12/2001		04/12/2001		04/12/2001		04/12/2001		04/12/2001	
	SDGNumber	40369		40369		40369		40369		40369	
Parameter	**Units**										
Vinyl chloride	ug/L	1.4	=	1.7	=	1	U	0.7	J	1	U
1,1-Dichloroethene	ug/L	1	U	1	U	1	U	1	U	1	U
trans-1,2-Dichloroethene	ug/L	1	U	0.35	J	1	U	1.6	=	1	U
1,1-Dichloroethane	ug/L	1	U	1	U	1	U	1	U	1	U
cis-1,2-Dichloroethylene	ug/L	2.9	=	4	=	0.6	J	14.8	=	1.1	=
1,1,1-Trichloroethane	ug/L	1	U	1	U	1	U	1	U	1	U
Trichloroethylene (TCE)	ug/L	7.6	=	11.9	=	0.26	J	34.7	=	1	U
Tetrachloroethylene (PCE)	ug/L	4.3	=	5.7	=	1	U	26.3	=	1	U

	StationID	E549GW003	
	SampleID	549GW003L1	
	DateCollected	04/06/2001 0:00	
	DateAnalyzed	04/12/2001	
	SDGNumber	40369	
Parameter	**Units**		
Vinyl chloride	ug/L	1	U
1,1-Dichloroethene	ug/L	1	U
trans-1,2-Dichloroethene	ug/L	1	U
1,1-Dichloroethane	ug/L	1	U
cis-1,2-Dichloroethylene	ug/L	0.98	J
1,1,1-Trichloroethane	ug/L	1	U
Trichloroethylene (TCE)	ug/L	1	U
Tetrachloroethylene (PCE)	ug/L	1	U

Appendix C

Material Safety Data Sheet

MFE063

[1] Product Identification

Product name	E−200
Manufacturer's name	Dowa Iron Powder Co.,Ltd
Manufacturer's address	7 Chikkosakaemachi Okayama City Japan
Emergency telephone number	086(262)2228
Telephone number for information	086(262)2228
Date prepared	Feb.1,2000
Signature of prepare	Koichi Maruoka

[2] Ingredients

Chemical name	Iron (Fe)	95wt%<
CAS No.	7439-89-6	

[3] Physical/Chemical Characteristic

Boiling point	2730℃
Melting point	1535℃
Vapor pressure	N.A.
Vapor density	N.A.
Particle size	75 μm
Specific gravity(H_2O=1)	7.8
Viscosity	N.A.
pH value	N.A.
Evaporation rate	N.A.
Solubility in water/other solvents	Negligible
Appearance/Odor	Dark gray powder/Odorless

[8] Protection Information

Respiratory protection	Preferable to put on single mask.
Eye protection	Preferable to put on goggles.
Protective gloves	Preferable to clothe gloves.
Other protective clothing or equipment	Eyewash equipment etc. as required by your company.
Ventilation	Good general ventilation should be sufficient for most conditions.
Work/Hygienic practices	Wash with water after handling.

[9] Precautions for Safe Handling and Use

Steps to be taken in case material is released or spilled	Sweep up and remove.
Waste disposal method	Dispose of the materials in accordance with local regulations as incombustible substance.
Precautions to be taken in handling and storing	Store in dry and cool place.
Other precautions	U

Appendix D

EPA COMMENTS ON
PHASE II CORRECTIVE MEASURES STUDY WORK PLAN
SWMU # 70, ZONE E
CHARLESTON NAVAL COMPLEX ANNEX
REVISION 0, OCTOBER 2001

OVERALL COMMENT

The use of zero valent iron (ZVI) technology is gaining acceptance in the industry in permeable barrier reactive walls, ex-situ groundwater treatment units and, as in this study, injected directly into the subsurface/groundwater. While the details regarding the injection process remain a bit unclear (see GENERAL COMMENT No. 2), the Agency is both skeptical and optimistic regarding the outcome of this Corrective Measure Study (CMS). It is recommended that this Work Plan be approved after the successful resolution of the following general and specific comments.

CH2M-Jones Response:
Comment noted. It should be noted that pneumatic fracturing, which is a primary component of the Ferox process, is not a new technology. It has been commercially available for ten years and has been well studied. Many of the review comments appear to be generated based on the reviewer probably being unfamiliar with this process. Information on the pneumatic fracturing process is readily available. One good source of information is the ARS Technology website (www.arstechnologies.com). Some of the review comments can also be more easily addressed in a phone conference with CH2M-Jones and ARS.

GENERAL COMMENTS

1. While there is some information presented in this work plan, there is not a clear, cohesive presentation of the overall geometry of the treatment zone. For example, the top of the local aquitard , the Ashley Clay, is shown in the accompanying boring logs as being 35 feet below land surface (bls) in the one boring within the treatment zone. The three other boring logs indicate the top of the Ashley approximately 23 feet bls. This subsurface variability over distances of 100± feet causes concern as to the application of a pressure-based technology. If the aquitard occurs at such variable elevations, it is not clear that the pressurized fracturing and injection would not breach the Ashley aquitard and mobilize the hexavalent chromium (Cr VI) into other lateral and/or deeper horizons.

CH2M-Jones Response:
The propagation characteristics of fractures resulting from pneumatic fracturing technology have been well evaluated during the period during its development in the 1980s, and since pneumatic fracturing was patented by the New Jersey Institute of Technology in 1991. The propagation of a fracture will preferentially follow a horizontal path of least resistance. If the propagation encounters a slope of the rising Ashley Formation, the propagation would preferentially follow the interface of the Ashley and

cause a corresponding compression/compaction (and corresponding reduction in permeability) somewhere else within the treatment zone, assuming near-zero surface heave. Secondly, is the treatment zone to be considered an 'open system'? In an open system, when the ZVI slurry is fed into the subsurface, there would be a corresponding displacement of Cr VI contaminated groundwater out of the treatment zone. Please provide case studies, if available, that document the effects and the effectiveness of these processes.

CH2M-Jones Response:
While some of the details of the pneumatic fracturing process are proprietary, some information about this technology can be found at www.arstechnologies.com.

The pneumatic fracturing process does result in surface heave (less than one-half inch at the initiation point and decreasing radially). A structural analysis of buildings in the injection area has been completed; the surface heave anticipated at the site is within the normal structural tolerances of the building design. When the propagation is initiated, the greatest fraction of the connate groundwater will be temporarily distributed above and below the fracture plane. Also, the process is initiated at the perimeter of the treatment zone, and moves inward in order to prevent mobilization of contaminants outside the treatment area.

The text states that nearby locations will be monitored for pressure increases (Page 3-7, Line 4). Pressure values are important so as to understand the radius of influence of a fracturing/injection event. A secondary effect of an event would be the change in the water table to create a mounding effect which in-turn would induce groundwater gradients and groundwater movement. Please provide case studies that point to the benefit of monitoring pressure only or monitoring the water table elevation or both. The current proposed action appears to require an element of regulatory trust with an eye towards the results of the fracturing/injection event being more important that the actual process for obtaining those results.

CH2M-Jones Response:
The necessary and appropriate pressure monitoring has been described in the Work Plan. Groundwater elevation monitoring is unnecessary. Any mounding that would be observed at the site would be temporary (i.e., less than 24-hours). Groundwater velocities at CNC are extremely low (e.g., less than 15-ft per year). Given the slow rate of groundwater movement and the minimal mounding period, there is not a likelihood of increased groundwater movement outside the treatment area. CH2M-Jones disagrees that the proposed process does not require "regulatory trust". However, a good understanding of the project site and the treatment process are necessary to evaluate the technology.

3. There is no discussion regarding groundwater movement in the SWMU 70/treatment zone area. There is no potentiometric map provided. Is there a significant groundwater

4. **Figure 2-1**. There is an irregular circle at the top center of the figure. Please explain the nature of this feature or remove it from the figure. Also there is a note that says that this figure was originally created in color. In the future, please include the figure as a color version or properly label and explain the features so as there would be no loss of information between a color and a black & white version.

CH2M-Jones Response:
The referenced circle is Area of Concern (AOC) 542. This AOC is not relevant to the project. The reference to the original figure being in color will be removed. The figure was prepared to be presented in a black and white format.

There appears to be typo between the sample numbers of the figure and the information in Appendix B, the analytical data summaries. For instance, it is believed that location E070GP002 on Figure 2-2 is equivalent to sample number E070VP002 in Appendix B. Please correct whichever portion of the work plan needs correction.

CH2M-Jones Response:
The above referenced assumption is correct. The figure will be corrected.

5. **Figures 2-2, -3, and -4**. Please include a note that defines what units are appropriate for the values on the figure. Also see the comments regarding color vs. black & white figures in Comment 4.

CH2M-Jones Response:
The requested note will be added to the referenced figures.

6. **Page 3-2, Line 4**. The text touts the Ferox^{SM} as better due to the ability to modify injection parameters to adapt to site conditions. These parameters are not described in this section or in the subsequent Section 3.3, Ferox^{SM} Injection Method. Please revise the text include a discussion of these parameters and how their modification provides an advantage.

CH2M-Jones Response:
The above referenced text is referring to the ability of the Ferox process to increase iron loadings in areas of higher contamination. Text to this affect will be included in the Rev 1 Work Plan.

7. **Page 3-2, Line 10**. The text describes numerous laboratory tests that demonstrate the superiority of the iron powder to be used in this test. Please revise the text to provide the data from these tests and a discussion of how this conclusion of superiority was reached.

into the header. Additionally, a legend for the various lithology types needs to be included. Please revise these logs as necessary.

CH2M-Jones Response:
The logs will be revised for the Revision 1 submittal.

12. **Appendix B**. Please check the analytical reports and revise these tables to include the proper units.

CH2M-Jones Response:
The proper units will be provided in the Rev 1 WP.