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CORRECTIVE MEASURES STUDY REPORT AREA OF CONCERN 607 (AOC 607), ZONE F
PILOT STUDY WORK PLAN CNC CHARLESTON SC
1/1/2006
CH2M HILL

CORRECTIVE MEASURES STUDY REPORT/PILOT STUDY WORK PLAN

AOC 607, Zone F



***Charleston Naval Complex
North Charleston, South Carolina***



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

PREPARED BY
CH2M-Jones

January 2006

Contract N62467-99-C-0960

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Revision 2
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Certification Page for Corrective Measures Study Report/Pilot Study Work Plan (Revision 2) – AOC 607, Zone F

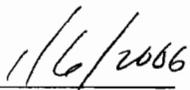
I, Dean Williamson, certify that this report has been prepared under my direct supervision. The data and information are, to the best of my knowledge, accurate and correct, and the report has been prepared in accordance with current standards of practice for engineering.

South Carolina

Permit No. 21428



Dean Williamson, P.E.



Date

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1 Acronyms and Abbreviations

2	AOC	area of concern
3	BCT	BRAC Cleanup Team
4	BRAC	Base Realignment and Closure
5	C ₃ H ₅ KO ₃	potassium lactate
6	CO ₂	carbon dioxide
7	CA	Corrective Action
8	CMS	Corrective Measures Study
9	CNC	Charleston Naval Complex
10	COC	chemical of concern
11	COPC	chemical of potential concern
12	CSAP	Confirmatory Sampling and Analysis Plan
13	CVOC	chlorinated volatile organic compound
14	DCE	dichloroethene
15	DHE	Dehalococcoides etheneogenes
16	DMP	Data Management Plan
17	DNAPL	dense non-aqueous phase liquid
18	DO	dissolved oxygen
19	DPT	direct-push technology
20	EnSafe	EnSafe Inc.
21	EPA	U.S. Environmental Protection Agency
22	ERD	enhanced reductive dechlorination
23	ERH	electrical resistance heating
24	ESDSOPQAM	Environmental Services Division <i>Standard Operating Procedures and</i>
25		<i>Quality Assurance Manual</i>
26	EVS	Environmental Visualization System
27	ft bls	foot below land surface
28	ft ³	cubic feet

1 Acronyms and Abbreviations, Continued

2	HI	hazard index
3	ILCR	incremental lifetime cancer risk
4	IM	interim measure
5	IMWP	interim measure work plan
6	ISCO	in situ chemical oxidation
7	KMnO ₄	potassium permanganate
8	kW	kilowatt
9	LUC	land use control
10	MCL	maximum contaminant level
11	MCS	media cleanup standard
12	MDL	Method Detection Limit
13	µg/L	microgram per liter
14	mg/L	milligrams per liter
15	MIP	membrane interface probe
16	MNA	monitored natural attenuation
17	NAPL	non-aqueous phase liquid
18	NAVBASE	Naval Base
19	NOM	natural organic matter
20	O&M	operation and maintenance
21	ORP	oxygen reduction potential
22	PCE	tetrachloroethene
23	PCR	Polymerase Chain Reaction
24	PCU	power control units
25	PLFA	phospholipid fatty acid
26	PSWP	Pilot Study Work Plan
27	QAP	Quality Assurance Plan
28	RAO	remedial action objective

1 **Acronyms and Abbreviations, Continued**

2	RCRA	Resource Conservation and Recovery Act
3	RFI	RCRA Facility Investigation
4	RGO	remedial goal option
5	RI	remedial investigation
6	SCDHEC	South Carolina Department of Health and Environmental Control
7	SOD	soil oxidant demand
8	TCB	trichlorobenzene
9	TCE	trichloroethene
10	TOC	total organic carbon
11	TTA	target treatment area
12	VFA	volatile fatty acids
13	VOC	volatile organic compound

SECTION 1.0

Introduction

1.0 Introduction

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

7 CNC Corrective Action (CA) activities are being conducted under the Resource
8 Conservation and Recovery Act (RCRA). The South Carolina Department of Health and
9 Environmental Control (SCDHEC) is the lead agency for CA activities at the site. All RCRA
10 CA activities are performed in accordance with the Final Permit (Permit No. SC0 170
11 022 560).

12 In April 2000, CH2M-Jones was awarded a contract to provide environmental investigation
13 and remediation services at the CNC. This submittal presents a Corrective Measures Study
14 (CMS) Report and a Pilot Study Work Plan (PSWP) for Area of Concern (AOC) 607 in Zone
15 F at the CNC. Figure 1-1 presents the location of AOC 607 within Zone F.

16 1.1 Purpose of the Corrective Measure Study Report/Pilot 17 Study Work Plan

18 This document contains two submittals – a CMS Report and a PSWP for the shallow interval
19 of the surficial aquifer. The CMS report evaluates CA alternatives for the chlorinated
20 solvents present in the shallow and deeper portions of the surficial aquifer at AOC 607 and
21 develops the basis for selection of a CA alternative that prevents contaminant migration,
22 ensures that exposure of the groundwater COCs to human and ecological receptors does not
23 occur, and can achieve a reduction in COC concentrations in groundwater over time.
24 Shallow groundwater at AOC 607 is defined as the surficial aquifer interval above the
25 competent clay layer located at an approximate elevation of 10 to 11 feet below land surface
26 (ft bls). Deeper groundwater is considered to occur from approximately 30 to 35 ft bls.

27 The CMS report also presents a summary of the Interim Measure (IM) completed at the site,
28 as documented in the *Interim Measure Completion Report/CMS Work Plan/Investigation Work*
29 *Plan, AOC 607, Zone F, Revision 0* (CH2M-Jones, 2003); a summary of the chemicals of
30 concern (COCs) that were identified at AOC 607; and the proposed media cleanup

1 standards (MCSs) for volatile organic chemicals (VOCs) in groundwater. The *CMS Work*
2 *Plan* evaluated and refined the COCs identified at AOC 607 (CH2M-Jones, 2003).

3 An IM that was previously implemented at the site targeted the removal of a suspected dry
4 cleaning solvent (tetrachloroethene [PCE]) from groundwater. PCE was previously used at
5 the facility as a dry cleaning solvent. PCE was suspected to be in the shallow aquifer in the
6 form of a dense non-aqueous phase liquid (DNAPL). Sites with groundwater contaminated
7 by chlorinated solvent DNAPLs are known to be very difficult and, in many cases, virtually
8 impossible to remediate to drinking water standards. Although the IM is believed to have
9 been successful in removing much or most of the PCE DNAPL from the aquifer, a small
10 amount of residual DNAPL may remain at the site. Residual DNAPL makes complete
11 restoration of the shallow aquifer to its original pristine condition a difficult and potentially
12 unachievable objective, especially within the short and intermediate term time frames. It is
13 expected to take many decades for the aquifer to reach its original unimpacted condition.
14 However, it is likely that decreases in dissolved phase COC concentrations can be achieved
15 at the site over time. The site can be managed such that the plume does not migrate further
16 and no human or ecological receptors are exposed to unacceptable concentrations of COCs.
17 This CMS focuses on how best to achieve these objectives at the site.

18 In addition, an additional deep monitoring well has been installed at the site to assess the
19 extent of contamination of the deeper portion of the shallow aquifer. If needed, additional
20 corrective measures will be evaluated to address contamination in this portion of the aquifer
21 under a separate CMS report. Analysis of the groundwater sample from the new deep well
22 indicates that the extent of VOC contamination in the deeper zone of the surficial aquifer is
23 limited to the vicinity of well F607GW018D.

24 The PSWP included with this CMS outlines the procedures for a site-specific test in the
25 shallow interval of the surficial aquifer at AOC 607 for the recommended remedial
26 technology for reducing the dissolved phase concentrations of VOCs (enhanced reductive
27 dechlorination).

28 **1.2 Background**

29 **1.2.1 Site History**

30 AOC 607 consists of a former dry cleaning facility, Building 1189, that supported the former
31 local seamen's housing from 1942 to 1986. Building 225, a former Naval Lodge, is located
32 immediately west of AOC 607. Toward the end of its operational period, the dry cleaning

1 facility was used as a general purpose laundry with two industrial washers and dryers.
2 PCE, a typical dry-cleaning solvent, was one of the primary materials that was used, stored,
3 disposed of, and accidentally released at the site. Trichloroethene (TCE), cis-1,2-
4 dichloroethene (cis-1,2-DCE), trans-1,2-dichloroethene (trans-1,2-DCE), and vinyl chloride,
5 which are sequential dechlorination products of PCE, were also detected in soil and
6 groundwater samples collected at AOC 607 during the RCRA Facility Investigation (RFI)
7 conducted by EnSafe Inc. (EnSafe) in 1996 and 1997. These investigation activities are
8 summarized in the *Zone F RFI Report, Revision 0* (EnSafe, 1997).

9 **1.2.2 General Source Area Description**

10 Based on the information presented in the RFI report and subsequent investigations, PCE
11 appeared to have migrated vertically downward as a DNAPL through fill and shallow
12 subsurface soils, until it encountered a clay unit at approximately 10 to 11 ft bls. The PCE
13 DNAPL appeared to have accumulated on top of and within the clay layer, providing a
14 residual source for the dissolved-phase chlorinated solvents that contaminate the shallow
15 groundwater. Left in that state, this DNAPL source area would be expected to contribute
16 dissolved phase contamination to the shallow groundwater for at least several decades into
17 the future.

18 Previous investigations at AOC 607 identified concentrations of PCE at or greater than 1
19 percent of the maximum solubility in water at several shallow monitoring well locations at
20 the site. The maximum solubility of PCE in water is approximately 200 milligrams per liter
21 (mg/L). The value of 1 percent or greater of the maximum solubility of a solvent in
22 groundwater is often used as an empirical indicator of the likely presence of a DNAPL near
23 the monitored location. Thus, concentrations of 2 mg/L (2,000 micrograms per liter [$\mu\text{g}/\text{L}$])
24 or greater of PCE in groundwater suggests the likely indicator of the presence of a DNAPL
25 source area near the monitored location at AOC 607.

26 The chlorinated solvent-impacted shallow groundwater is believed to be generally
27 hydraulically controlled by a sanitary sewer line located southwest of Building 1189. The
28 sanitary sewer line has created a depression in the potentiometric surface that appears to
29 have slowed or prevented lateral contaminant migration of dissolved phase contamination.
30 Figure 1-2 presents the physical setting at AOC 607, including the sanitary sewer and
31 monitoring well locations. Figures 1-3 through 1-5 depict the shallow, intermediate, and
32 deep groundwater potentiometric surfaces, respectively, using water elevations collected on
33 March 13, 2003.

1.3 Report Organization

This CMS report/PSWP consists of the following sections, including this introductory section:

1.0 Introduction – Presents the purpose and scope of the CMS Report and PSWP, as well as relevant background information, including site history and a description of the source area within the shallow portion of the surficial aquifer.

2.0 Site Condition Summary – Presents a site-specific summary of existing conditions, including site geology and hydrogeology, nature and extent of contamination, and a summary of the risk assessment, and most notably the groundwater COCs identified at the site.

3.0 RAOs, Proposed MCSs, and Alternative Evaluation Criteria – Presents the remedial action objectives (RAOs) of this CMS and the proposed MCSs for VOCs in groundwater.

4.0 Description of Candidate Corrective Measure Alternatives – Describes each of the candidate corrective measure alternatives for contaminant concentration reduction in the shallow interval of the surficial aquifer.

5.0 Detailed Analysis of Alternatives – Presents the applicable treatment technologies considered for groundwater remediation and a description of the technology screening process. The section also summarizes the factors and methodology used to evaluate and rank the corrective measure alternatives and the results of the evaluation.

6.0 Recommended Corrective Measure Alternative – Describes the preferred corrective measure alternative to achieve the MCSs and remedial goal options (RGOs) for contaminant concentration reduction at AOC 607, based on a comparison of the alternatives.

7.0 Pilot Study Work Plan – Presents the approach for evaluating the site-specific technology effectiveness in the shallow interval of the surficial aquifer.

8.0 References – Lists the references used in this document.

Appendix A provides the cost estimates for each corrective measure alternative evaluated in this CMS.

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

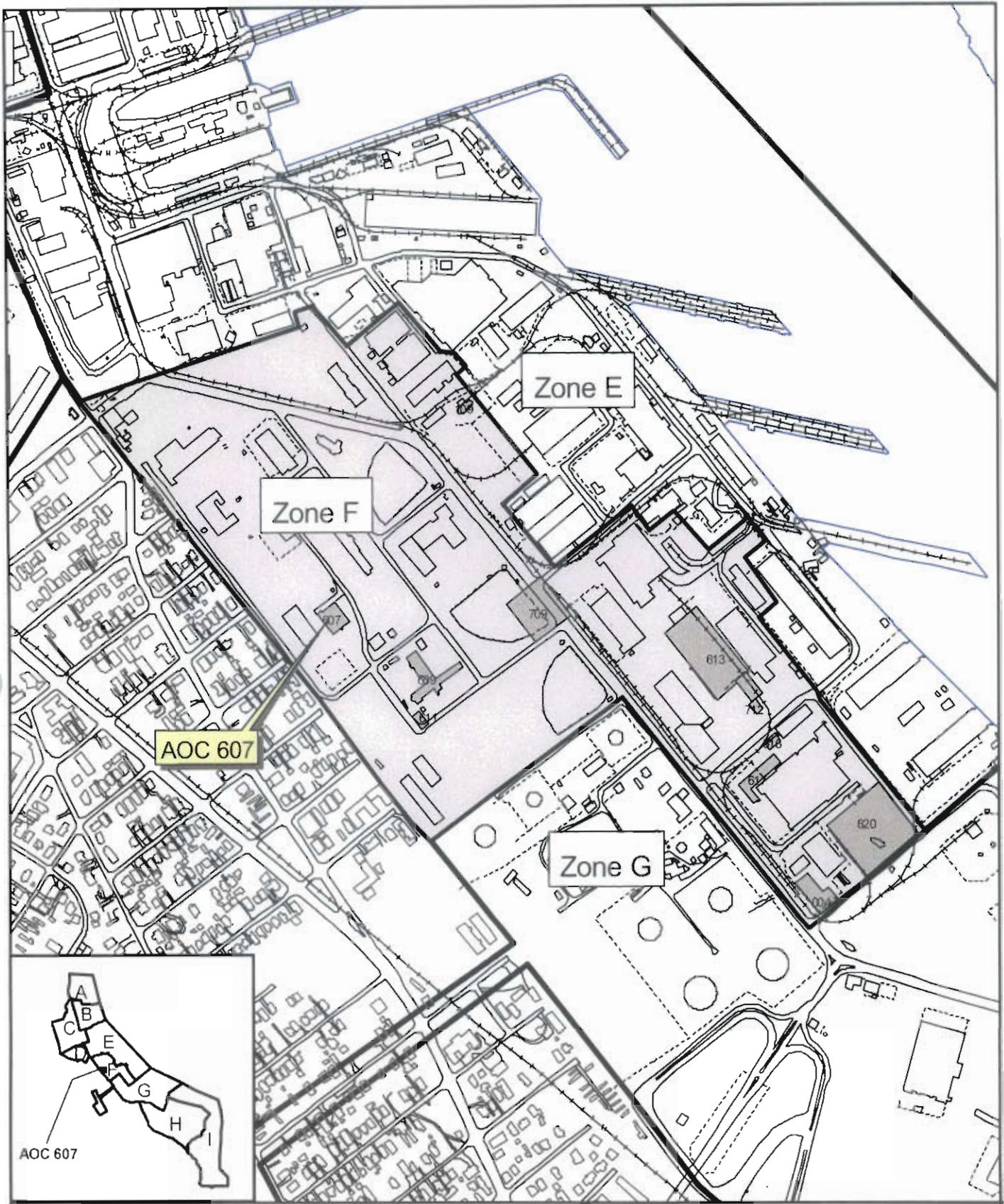


Figure 1-1
 Location of AOC 607 in Zone F
 AOC 607, Zone F
 Charleston Naval Complex



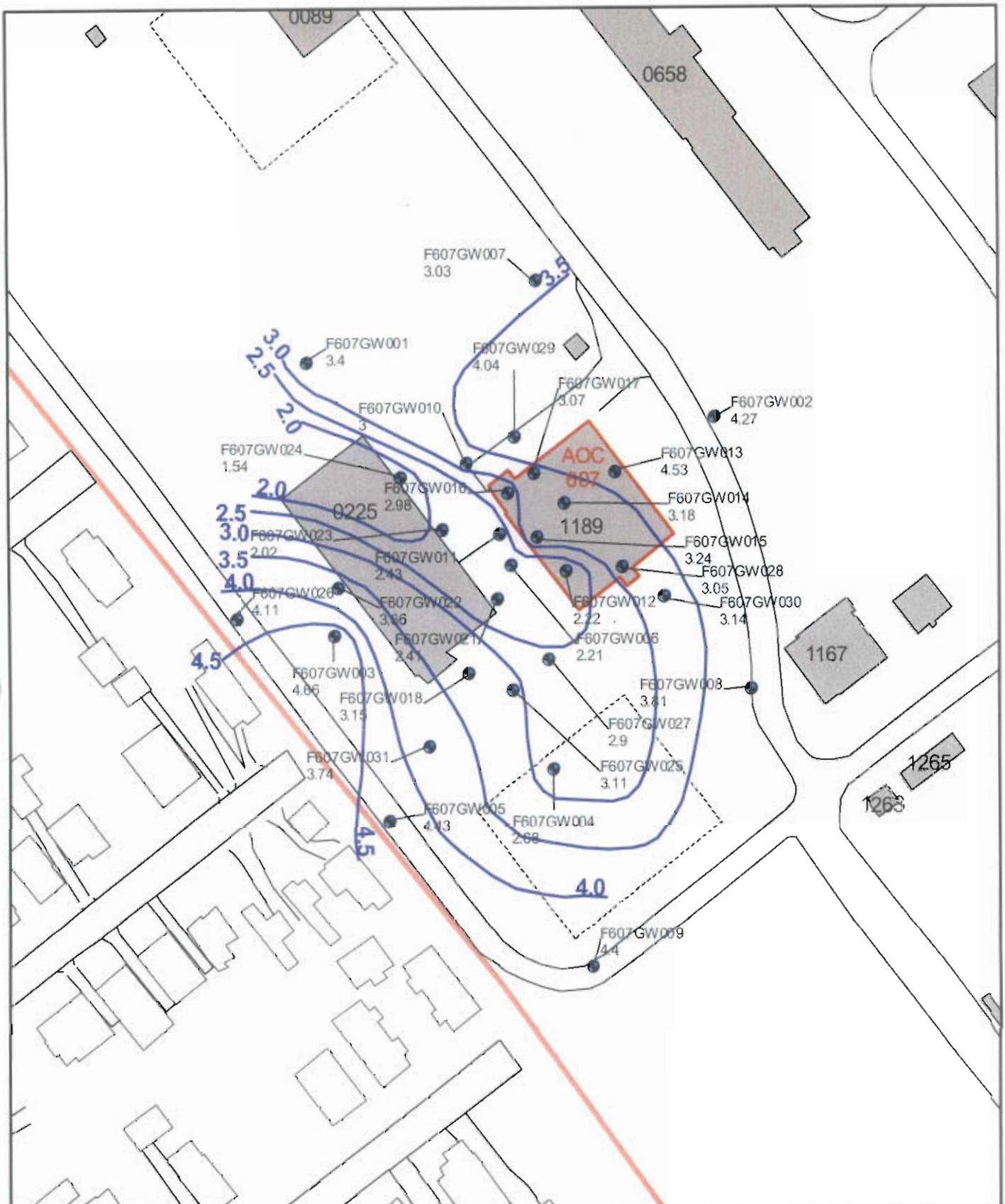
- Monitoring Well
- Fence
- Roads
- STORM-LINE/MANHOLE
- SEWER-LINE/MANHOLE

- AOC Boundary
- Buildings
- Zone Boundary

0 80 160 Feet
 1 Inch = 100 feet



Figure 1-2
 Site Location Map
 AOC 607, Zone F
 Charleston Naval Complex



- Monitoring Well (Groundwater Elevations in ft msl)
- ~ Groundwater Contours .5 ft interval (March 13, 2003)
- - - Fence
- == Roads
- ▭ AOC Boundary
- ▭ Buildings
- ▭ Zone Boundary

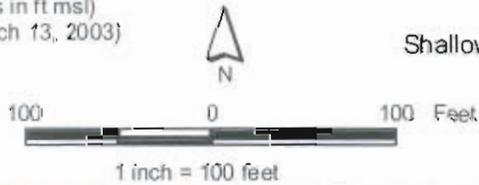


Figure 1-3
 Shallow Groundwater Potentiometric Surface
 AOC 607, Zone F
 Charleston Naval Complex

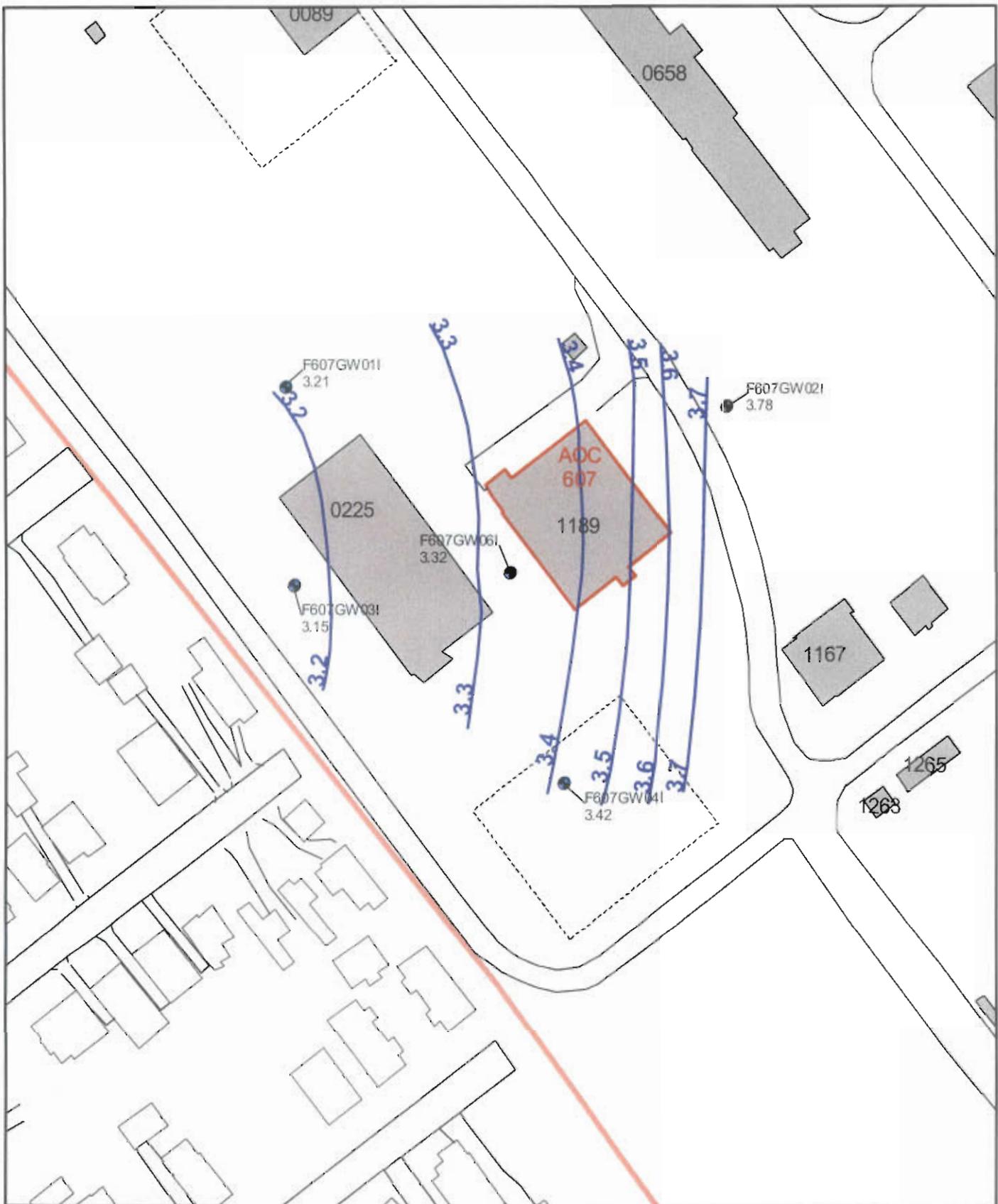


Figure 1-4
 Intermediate Groundwater Potentiometric Surface
 AOC 607, Zone F
 Charleston Naval Complex

- Monitoring Well (Groundwater Elevations in ft msl)
- ~ Groundwater Contours .2 ft interval (March 13, 2003)
- /- Fence
- /- Roads
- ▭ AOC Boundary
- ▭ Buildings
- ▭ Zone Boundary

100 0 100 Feet
 1 inch = 100 feet

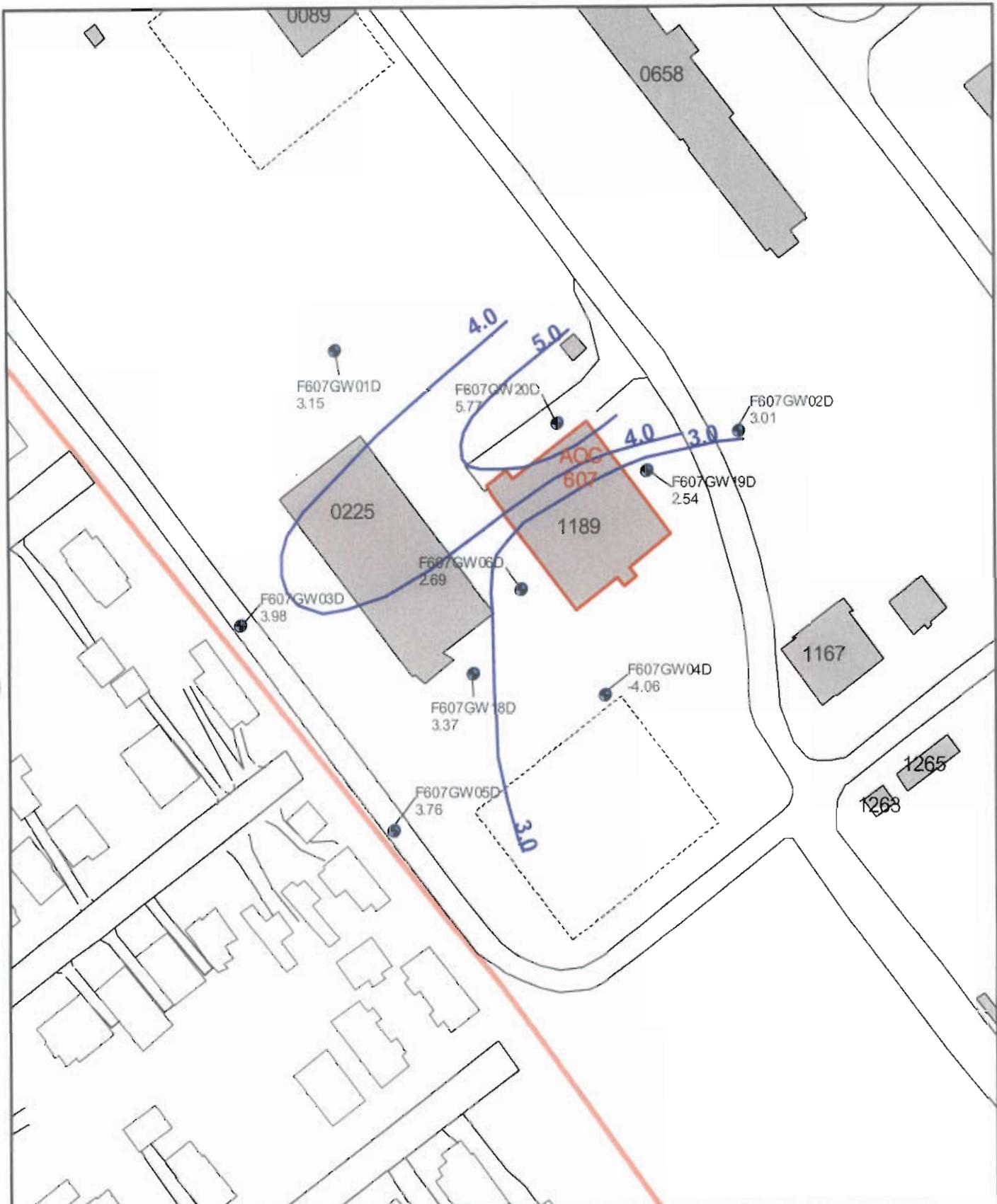
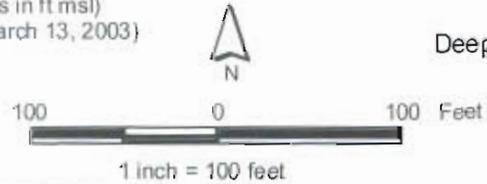


Figure 1-5
 Deep Groundwater Potentiometric Surface
 AOC 607, Zone F
 Charleston Naval Complex

- Monitoring Well (Groundwater Elevations in ft msl)
- Groundwater Contours 1.0 ft interval (March 13, 2003)
- - - Fence
- Roads
- ▭ AOC Boundary
- ▭ Buildings
- ▭ Zone Boundary



SECTION 2.0

Site Conditions Summary

2.0 Site Conditions Summary

This section presents a summary of existing site conditions, including site geology and hydrogeology, completed source area IM activities, the risk assessment as documented in the *Zone F RFI Report, Revision 0* (EnSafe, 1997), and the groundwater COCs identified in the surficial aquifer at AOC 607.

2.1 Site Geology

The geology of the Zone F area is typical of the Atlantic Coastal Plain geology observed in other zones at the CNC. The surface soils of Zone F have been significantly disturbed by development of the base, and most of the native soils are covered by buildings and other improvements, pavement, and/or fill materials. Exposed surface soil in undisturbed areas consist of recent and/or Pleistocene age sands, silts, and clays, all with relatively high organic content. Where dredged material from the Cooper River and Shipyard Creek have been used as fill, the surface materials consist of unsorted mixtures of sand, silts, and clays. The subsurface geology consists of varying amounts of fill material to depths of up to approximately 5 ft bls, underlain by undifferentiated Quaternary age sands, silts, and clays of the Wando Formation to approximately 20 to 25 ft bls. These deposits are comprised of discontinuous clay layers and lensatic sands in many locations, with many minor alternating interbeds of 1 foot or less in thickness.

The Quaternary deposits are in turn underlain by undifferentiated Tertiary age marine silt. The marine silt is fossiliferous, with significant phosphatic content, and its thickness varies between approximately 10 feet and 20 feet in Zone F. The Tertiary age Ashley Formation is associated with and underlies the undifferentiated Tertiary marine silt, unconformably in some places. The Ashley Formation consists of a slightly calcareous clayey silt, and overlies the Eocene age Santee Limestone of the Cooper Group, which was not encountered during the Zone F investigations.

2.2 Site Hydrology and Hydrogeology

The surface hydrology of Zone F is controlled by a system of storm sewers and drainage swales, which in turn drain east through Zone E to the Cooper River. The local hydrogeology consists of an unconfined aquifer system within the Quaternary deposits, with the underlying Ashley Formation acting as a lower bounding unit. The unconfined

1 aquifer varies in total thickness from approximately 21 to 35 feet thick in Zone F. Depth to
2 groundwater is typically 4 to 5 ft bls.

3 Because of the heterogeneity of the Quaternary deposits, the hydraulic properties of the
4 shallow (surficial) aquifer system vary widely, depending on location and depth. The locally
5 variable hydraulic gradients and hydraulic conductivity measured in wells result in variable
6 groundwater flow rates and directions on a localized scale. Overall, the shallow
7 groundwater flow direction in Zone F is to the northeast, to the Cooper River. Tidal
8 influence on water levels in the shallow aquifer was reported to be minimal.

9 The hydraulic conductivity of the aquifer in shallow wells was determined during the Zone
10 F RFI to average 0.44 feet per day (ft/d). Groundwater flow velocities were found to average
11 approximately 0.01 ft/d, or generally less than 5 feet per year (ft/yr). Intermittent localized
12 groundwater divides were postulated during the RFI, possibly resulting from man-made
13 influences, such as groundwater and/or stormwater infiltration, leakage in storm sewers, or
14 concentrated local recharge from paved area runoff.

15 The Ashley Formation also acts as an upper confining unit for the Santee Limestone, which
16 is under artesian conditions and is used as a source of potable water. The average vertical
17 permeability of the Ashley Formation obtained by EnSafe from Shelby tube samples
18 collected during the adjacent Zone E RFI was approximately 0.03 ft/d, which is
19 representative of a confining unit.

20 A conceptualized geologic cross section of the subsurface in the vicinity of Building 1189 is
21 presented in Figure 2-1. The cross section shows the stratigraphic relationships between the
22 various geologic units encountered, the approximate thickness and extent of each unit
23 where known, and the relative position of Building 1189.

24 Figures 1-3 through 1-5, which depict the shallow, intermediate, and deep groundwater
25 potentiometric surfaces, respectively, are presented in Section 1.0 of this document. These
26 figures were created using water elevations collected on March 13, 2003.

27 **2.3 Phase I and II IM Summary**

28 The BRAC Cleanup Team (BCT) agreed to implement an IM to treat the aquifer that
29 appeared to contain a PCE DNAPL source area. A Phase I IM Work Plan (IMWP) entitled
30 the *Phase I Interim Measure Work Plan, Groundwater Investigation, AOC 607, Zone F, Revision 0*
31 (CH2M-Jones, 2001a) was executed in April 2001 to delineate the extent of the PCE source
32 area in the asphalt parking lot located between Buildings 225 and 1189 and inside the

1 southern portion of Building 1189. The Phase I source area delineation activities were
2 summarized in an appendix to the *Phase II Interim Measure Work Plan, PCE Source Area*
3 *Delineation, Area of Concern 607, Zone F, Revision 0* (CH2M-Jones, 2001b). This Phase II IMWP
4 outlined a second investigation to characterize the PCE source area south of Building 225
5 and immediately north and south of the former dry cleaning facility, Building 1189. During
6 the April and June 2001 investigations, the PCE source area was further characterized in 24
7 locations by the initial use of a membrane interface probe (MIP) soil conductivity tool,
8 followed by the collection of 40 groundwater samples from direct-push technology (DPT)
9 points advanced adjacent to the MIP locations. PCE was detected at a maximum
10 concentration of 120,000 µg/L, suggesting the presence of a DNAPL. Information obtained
11 from the Phase I and II source delineation activities was used to identify the target treatment
12 area (TTA) to be addressed using the electrical resistance heating (ERH) process.

13 VOC contamination in the deeper portion of the surficial aquifer has been found to be
14 limited to the vicinity of well F607CW018D. Concentrations of total VOCs in this well have
15 generally been in the 1,500 to 2,000 µg/L range. The data indicate that no DNAPL
16 penetration into the deeper zone of the surficial aquifer has occurred at AOC 607. Because of
17 the limited areal extent of the portion of the deeper surficial aquifer impacted and relatively
18 low concentrations, an IM in this zone was not considered necessary.

19 **2.4 Phase III IM Summary**

20 The objective of the Phase III IM was to implement ERH technology for reduction of the
21 existing chlorinated solvent source area at AOC 607. The TTA was defined on the basis of a
22 total chlorinated solvent concentration greater than 2,000 µg/L in the groundwater samples
23 collected at the site. The focus for the implementation of the IM using the ERH technology
24 was the saturated zone above the existing clay unit, which underlies the site at an
25 approximate depth ranging from 10 to 11 ft bls. ERH system operation and the results from
26 the performance monitoring events to evaluate system effectiveness are summarized in the
27 *Interim Measure Completion Report/CMS Work Plan/Investigation Work Plan, AOC 607, Zone F,*
28 *Revision 0* (CH2M-Jones, 2003).

29 **2.4.1 ERH Operation**

30 Thermal Remediation Services, Inc. (Thermal) was subcontracted to design, construct, and
31 operate the ERH system within the 16,525 square foot (ft²) TTA. The *Phase III Interim*
32 *Measure Work Plan, Electrical Resistance Heating – Source Area Remediation, AOC 607, Zone F,*
33 *Revision 0* (CH2M-Jones, 2001c) outlined the proposed construction and implementation

1 approach. The ERH system was constructed in August and September 2001, started on the
2 afternoon of October 3, 2001, and shut down on the morning of July 8, 2002.

3 The ERH system used two 500 kilowatt (kW) power control units (PCU 500-1 and PCU
4 500-2). The original design included 97 electrodes installed to a depth of approximately 10 to
5 10.5 ft bls. The site was divided into two portions based on when the PCUs were used. The
6 more contaminated southern portion began heating on October 3, 2001. The northern
7 portion of the site, which included the asphalt parking area outside Buildings 1189 and 225
8 and immediately north of monitoring well F607GW011, and the area immediately north of
9 F607GW014 located inside Building 1189, began operation on December 13, 2001.

10 The operation of the ERH system increased from the original design duration of 124 days to
11 279 days. The extension was due to the drying of the soils in the immediate area around
12 each electrode, which made the saturated zone less conductive. As a result, various
13 improvements were made to the electrode design and spacing from October 2001 to April
14 2002. From April 15 to May 15, 2002, the entire ERH system was operating using 101
15 electrodes, 12 8-inch diameter steel piles, 6 Geoprobe electrodes, and 310 3/4-inch diameter
16 ground rods.

17 **2.4.2 Recovered Contaminant Mass**

18 Total chlorinated volatile organic compounds (CVOCs) and PCE mass recovered during
19 ERH system operation was calculated at 247 and 234 pounds, respectively, using the SVE
20 influent samples collected during the 9-month IM. The total CVOC concentration is a
21 summation of PCE, TCE, cis-1,2-DCE, 1,1-DCE, and vinyl chloride concentrations. Most of
22 this mass was concluded to have likely been present in DNAPL form in the subsurface.

23 **2.4.3 Performance Monitoring Strategy**

24 Groundwater samples collected as part of the IM were used to evaluate ERH system
25 performance and to monitor potential contaminant migration during system operation.
26 Groundwater samples were collected from 12 shallow monitoring wells within the ERH
27 TTA and analyzed for VOCs using U.S. Environmental Protection Agency (EPA) method
28 8260B. The monitoring wells located in the TTA are provided in Figure 2-2.

29 To evaluate any effects of the ERH technology on the lower portions of the surficial aquifer
30 above the Ashley Formation and within the TTA, groundwater samples were collected from
31 intermediate and deep monitoring wells F607GW06I and F607GW06D, which are located
32 adjacent to monitoring well F607GW006. The analytical results obtained from the samples

1 collected from these wells were not used in calculating percent reduction in the dissolved
2 phase, since they are not screened in the ERH TTA.

3 The 14 monitoring wells inside the ERH TTA were sampled in September 2001, prior to
4 ERH system startup; monthly from February 2002 until immediately following system
5 shutdown in July 2002; and in January 2003, six months following shutdown. In addition,
6 six of the monitoring wells were sampled in the southern portion of the TTA in January
7 2002.

8 Perimeter groundwater monitoring was conducted to monitor VOC concentrations in the
9 peripheral areas outside the target ERH treatment area. Seven shallow monitoring wells
10 outside the TTA were sampled in September 2001, monthly during system operation, and in
11 January 2003. As part of the January 2003 sampling event, five additional shallow, four
12 intermediate, and eight deep monitoring wells outside the TTA were sampled and analyzed
13 for VOCs. These groundwater monitoring wells are also shown on Figure 2-1.

14 **2.4.4 Performance Monitoring Results**

15 **Inside the ERH Target Treatment Area**

16 Analytical results from the 12 shallow wells sampled during the January 2003 sampling
17 event were compared to the results from the initial sampling event completed in September
18 2001. The overall dissolved-phase VOC reduction, using the total summation of detected
19 concentrations of chlorinated solvents from the 12 shallow wells, was only 21 percent
20 (largely due to detection of 1,2,-DCE in one well after completion of the ERH
21 activities). Overall PCE reduction was 64.8 percent. Analytical results from the samples
22 collected from the 12 shallow and 2 intermediate or deep wells within the TTA during the 9
23 sampling events are summarized in Table 2-1.

24 Using the September 2001 data, the total dissolved CVOC concentration summation
25 consisted of 76 percent of PCE. This level decreased to 33.9 percent after 6 months, following
26 ERH system shutdown (i.e., January 2003 data). The small overall total CVOC reduction in
27 relation to the larger PCE concentration reduction can be attributed to the increase
28 (rebound) in cis-1,2-DCE concentration (i.e., 29,000 µg/L) in monitoring well F607GW028.
29 This large increase in cis-1,2-DCE concentration indicates reductive dechlorination of PCE
30 during the 6 months (i.e., July to December 2002) since the ERH system was shut down.

31 Four of the 12 shallow monitoring wells (F607GW015, F607GW016, F607GW017, and
32 F607GW029) had a decrease in total CVOC dissolved concentration greater than 90 percent
33 compared to the results from the September 2001 sampling event. Monitoring well

1 F607GW021 had a total CVOC reduction of 88.7 percent, and six of the remaining seven
2 wells showed a total CVOC reduction ranging from 5.5 percent (F607GW028) to 54.3 percent
3 (F607GW025). Nominal percent reduction in monitoring well F607GW028 is due to
4 reductive dechlorination and the elevated cis-1,2-DCE concentration of 29,000 µg/L.

5 Using the groundwater data from the September 2001 sampling event, the Environmental
6 Visualization System (EVS) software calculated a total CVOC dissolved plume volume of
7 0.017 cubic feet (ft³) and a mass of 1.698 pounds at a total concentration of 1,000 µg/L or
8 greater within the TTA. The total CVOC plume is a summation of PCE, TCE, cis-1,2-DCE,
9 1,1-DCE, and vinyl chloride concentrations. The PCE volume estimate is identical to the
10 total CVOC estimate, while the total CVOC mass estimate is comprised of 1.685 pounds of
11 PCE at the same concentration of 1,000 µg/L or greater. When the analytical results from the
12 January 2003 sampling event are compared to the results from the September 2001 sampling
13 event, the total CVOC volume and mass at a concentration of 1,000 µg/L or greater
14 decreased by 33.8 percent (i.e., cubic feet and pounds). PCE volume and mass at a
15 concentration of 1,000 µg/L or greater decreased to 41.2 percent (i.e., cubic feet and pounds).
16 Figures 2-3 and 2-4 present the pre- (i.e., September 2001) and post- (i.e., January 2003) 3-D
17 data interpretations of total CVOCs and PCE in the shallow portion of the surficial aquifer.

18 **Outside the ERH Target Treatment Area**

19 January 2003 analytical results from the samples collected from the seven monitoring wells
20 outside the ERH TTA were compared to the analytical results from the September 2001
21 sampling event. During the January 2003 sampling event, groundwater samples collected
22 from monitoring wells F607GW004 and F607GW007 had detected contaminant
23 concentrations. The only contaminant detected in the sample collected from F607GW007
24 was 1,2,4-trichlorobenzene (1,2,4-TCB) at a concentration of 0.59J µg/L. Cis-1,2-DCE,
25 detected at a concentration of 1.8J µg/L, was the only contaminant found in the sample
26 collected from F607GW004. This value is two orders of magnitude less than the
27 concentration of 130 µg/L detected in the sample collected during the September 2001
28 sampling event. In addition, trans-1,2-DCE, TCE, and vinyl chloride detected in the sample
29 collected from monitoring well F607GW004 during the September 2001 sampling event
30 were not detected above laboratory Method Detection Limits (MDLs) in the January 2003
31 sampling event. Analytical results from the samples collected from these seven wells
32 outside the TTA and the 17 additional shallow, intermediate, and deep wells sampling
33 during the January 2003 sampling event are summarized in Table 2-2.

1 Overall CVOC contaminant concentrations decreased in the seven shallow monitoring wells
2 outside the ERH TTA when compared to the results from the September 2001 and October
3 2003 sampling events. This substantiates that the surficial aquifer outside the ERH TTA was
4 not impacted from system operation and that contaminant migration did not occur during
5 ERH system operation.

6 **2.4.5 Evaluation of the IM Results**

7 Operation of the ERH system was considered successful in reducing DNAPL, to the extent
8 practicable. EVS software calculated approximately 1.7 pounds of total CVOCs at a
9 concentration greater than 1,000 µg/L in the dissolved phase prior to system startup. When
10 comparing the 1.7 pounds in the dissolved phase with the 247 pounds of CVOC recovered
11 mass from the SVE system, it is clear that the change in dissolved phase mass cannot
12 account for the 247 pounds of VOCs removed from the subsurface. The additional VOC
13 mass could have come from the vadose zone, from VOCs adsorbed to soil, or from DNAPL
14 within the aquifer. It is believed that most of the 247 pounds of VOCs recovered from the
15 subsurface most likely came from DNAPL at the site.

16 The nine-month ERH system operation was also effective in reducing the volume and mass
17 of the dissolved CVOC contaminant plume. The total CVOC volume and mass at a
18 concentration of 1,000 µg/L or greater decreased by 33.8 percent when calculated using EVS
19 software. PCE volume and mass at a concentration of 1,000 µg/L or greater decreased to
20 41.2 percent.

21 When comparing the analytical results from sampling events in January 2003 and
22 September 2001, the overall PCE concentration reduction is approximately 65 percent, with
23 5 of the 12 individual monitoring wells within the TTA achieving a total CVOC dissolved
24 concentration reduction of greater than 88 percent.

25 **2.5 Groundwater COCs**

26 Groundwater COCs in the surficial aquifer as identified in the *Interim Measure Completion*
27 *Report/CMS Work Plan/Investigation Work Plan, AOC 607, Zone F, Revision 0* (CH2M-Jones,
28 2003) include five CVOCs: 1,1-DCE, PCE, TCE, cis-1,2-DCE, and vinyl chloride. The extent
29 of these groundwater COCs has been defined through site monitoring wells in the shallow,
30 intermediate, and deeper portions of the surficial aquifer. Analytical data from samples
31 collected during the January 2003 sampling event were used to depict the distribution of

1 total CVOCs and PCE at 6 months following ERH system shutdown in the shallow portion
2 of the aquifer, as shown on Figures 2-5 and 2-6, respectively.

3 **2.6 Summary of Risk Assessment**

4 A human health risk assessment for AOC 607 was performed and documented in the *Zone F*
5 *RFI Report, Revision 0* (Section 10.4.8) for chemicals of potential concern (COPCs) that had
6 been identified in the preliminary screening process. According to the RFI risk assessment,
7 impacted environmental media at AOC 607 included surface soil and groundwater. The RFI
8 risk assessment evaluated exposure to surface soil on site under both the unrestricted
9 (residential) and site worker (industrial) land use scenarios: dermal contact with
10 contaminated surface soil, incidental ingestion of surface soil, inhalation of volatiles
11 emanating from surface and subsurface soils, ingestion of groundwater through potable use,
12 and inhalation of VOCs resulting from domestic or process use of groundwater.

13 In the RFI report, any chemical contributing to a cumulative risk level of 1E-06 or greater
14 and/or a cumulative hazard index (HI) greater than 1.0 and which had an incremental
15 lifetime cancer risk (ILCR) that exceeded 1E-06 or a hazard quotient that exceeded 0.1 was
16 considered a COC. This is conservative for carcinogenic compounds, because a cumulative
17 risk level of 1E-04 and individual ILCR of 1E-06 is recommended by the EPA as a trigger
18 level for establishing COCs.

19 The COCs that were identified for AOC 607 and documented in the *Zone F RFI Report,*
20 *Revision 0* (EnSafe, 1997) as needing further evaluation through a CMS were evaluated in
21 Section 6.0 of the *Interim Measure Completion Report/CMS Work Plan/Investigation Work Plan,*
22 *AOC 607, Zone F, Revision 0* (CH2M-Jones, 2003). The COCs identified in the *Zone F RFI*
23 *Report, Revision 0* were presented and re-evaluated to select a final set of COCs to be
24 addressed by this CMS. No surface or subsurface soil COCs were identified in the *Zone F*
25 *RFI Report, Revision 0*.

26 As a result of the COC refinement, the chemicals retained as COCs for shallow,
27 intermediate, and deep groundwater at AOC 607 are PCE, TCE, cis-1,2-DCE, and vinyl
28 chloride. 1,1-DCE was also retained as a shallow and intermediate groundwater COC.

Table 2.2
 Analytes Detected in Groundwater Monitoring Wells Outside of the ERH Target Treatment Area
 CMS Report/Pilot Study Work Plan, AOC 607, Zone F, Charleston Naval Complex

Monitoring Well Location/ Contaminant	Date	1,1-DCE (ug/L)	trans 1,2- DCE (ug/L)	cis-1,2-DCE (ug/L)	1,2-DCE (total) (ug/L)	TCE (ug/L)	PCE (ug/L)	Vinyl chloride (ug/L)	Carbon Disulfide (ug/L)	Methylene Chloride (ug/L)	Benzene (ug/L)	Toluene (ug/L)	Acetone (ug/L)	1,2,3-TCB (ug/L)	1,2,4-TCB (ug/L)	1,1-DCA (ug/L)	Chlorobenzene (ug/L)	1,4-DCB (ug/L)	1,2-DCA (ug/L)
1607GW03D	01/10/2003	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
1607GW04I	01/14/2003	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
1607GW04D	01/14/2003	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
1607GW05D	01/13/2003	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
1607GW18D	01/14/2003	7.0U	5.0U	250	250	240	1,300	9.5U	50U	50U	50U	50U	100U	50U	50U	50U	50U	50U	50U
1607GW19D	01/13/2003	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
1607GW20D	01/13/2003	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U

Notes:

- 1,1-DCE - 1,1-Dichloroethene
- trans-1,2-DCE - trans-1,2-Dichloroethene
- cis-1,2-DCE - cis-1,2-Dichloroethene
- TCE - Trichloroethene
- PCE - Tetrachloroethene
- 1,2,3-TCB - 1,2,3-Trichlorobenzene
- 1,2,4-TCB - 1,2,4-Trichlorobenzene
- 1,1-DCA - 1,1-Dichloroethane
- 1,4-DCB - 1,4-Dichlorobenzene

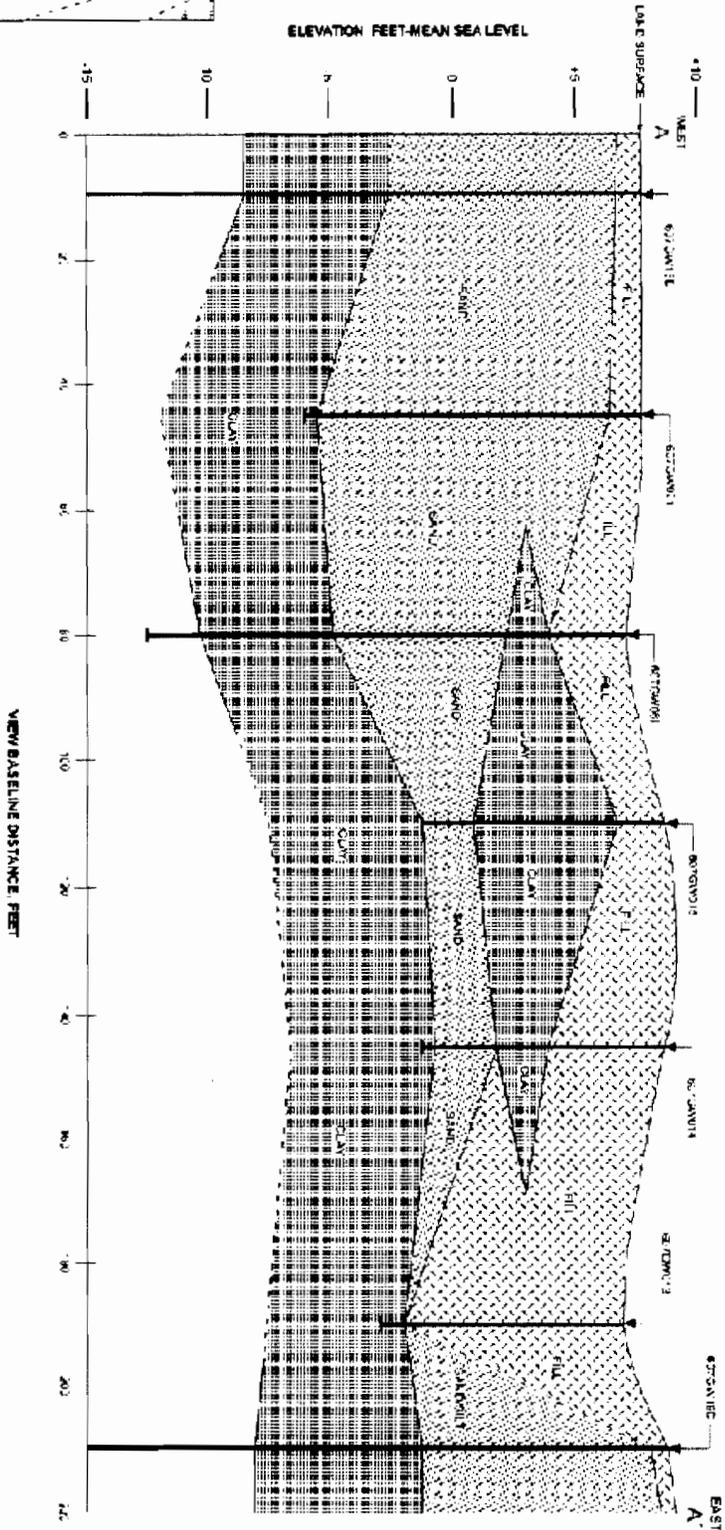
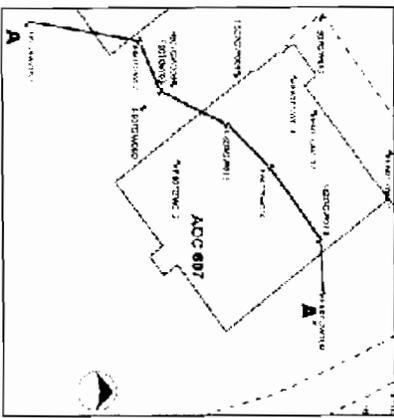
A number represented in bold text is an estimated concentration or a detected concentration above the method detection limit.

ug/L - micrograms per liter

U - contaminant not detected above laboratory detection limit

J - indicates an estimated value. A "J" qualifier may signify that the concentration is below the POL or that the "J" has been applied as a result of the data validation process, and to consider the numeric value as estimated.

B - target parameter was also detected in the laboratory method blank



VERTICAL SCALE = 1"=5'
 HORIZONTAL SCALE = 1"=20'
 VERTICAL EXAGGERATION = 4:1
 NOTE: LITHOLOGIC CONTACT LINES ARE INFERRED WHERE DASHED

Figure 2-1
 Lithologic Cross Section A-A
 AOC 607 Phase III/IV Work Plan
 Charleston Naval Complex
 CH2MHILL

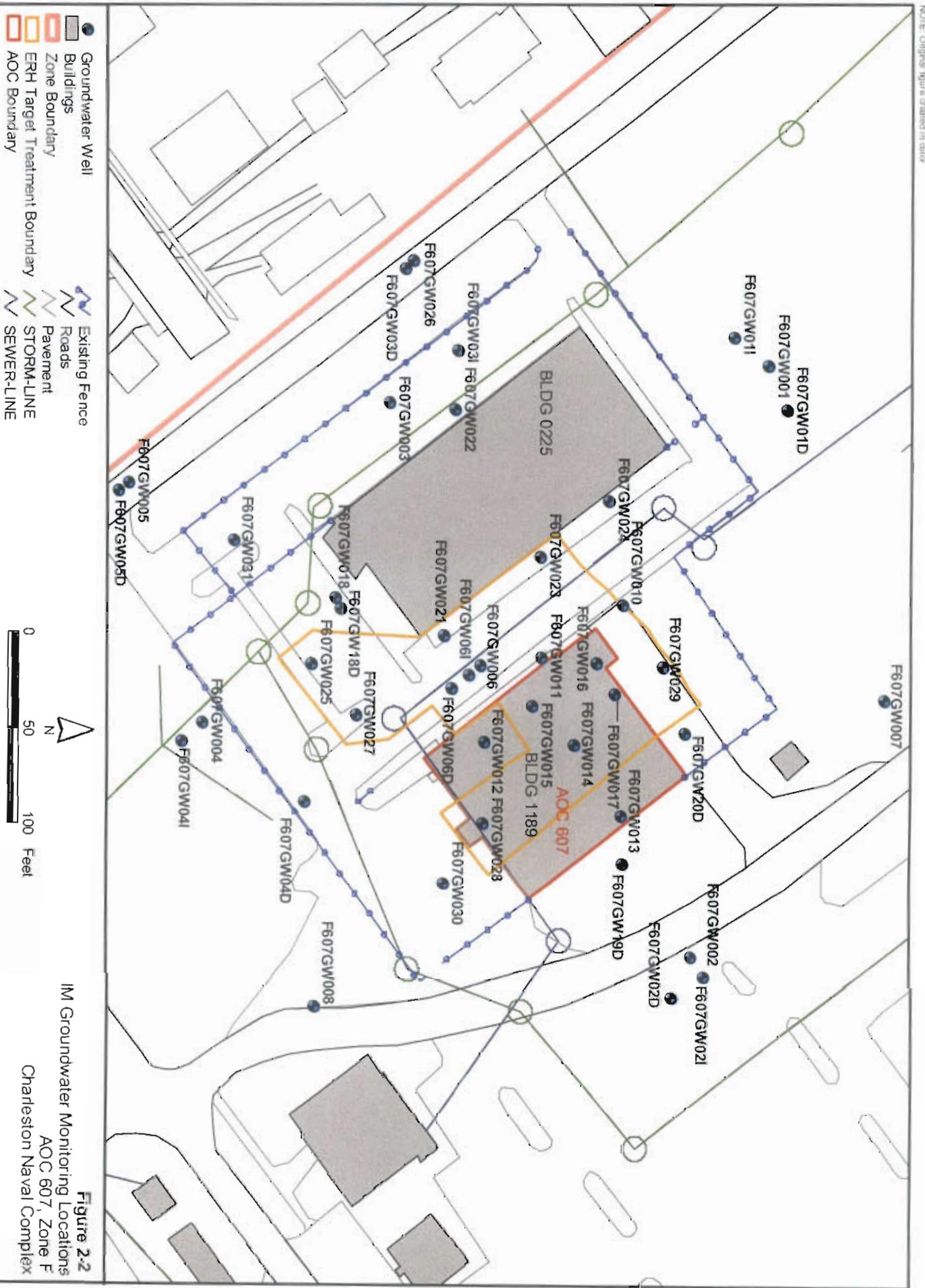
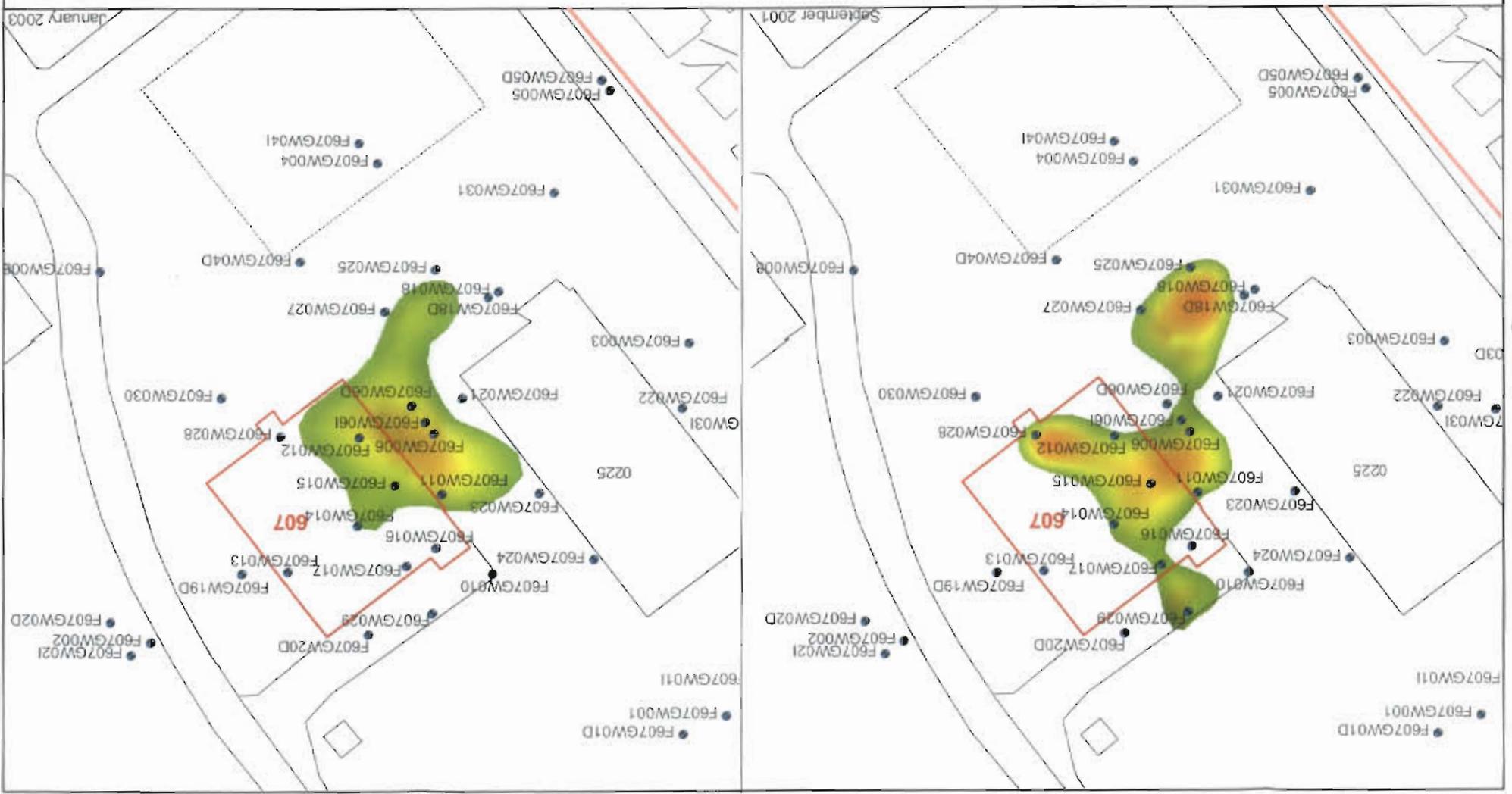
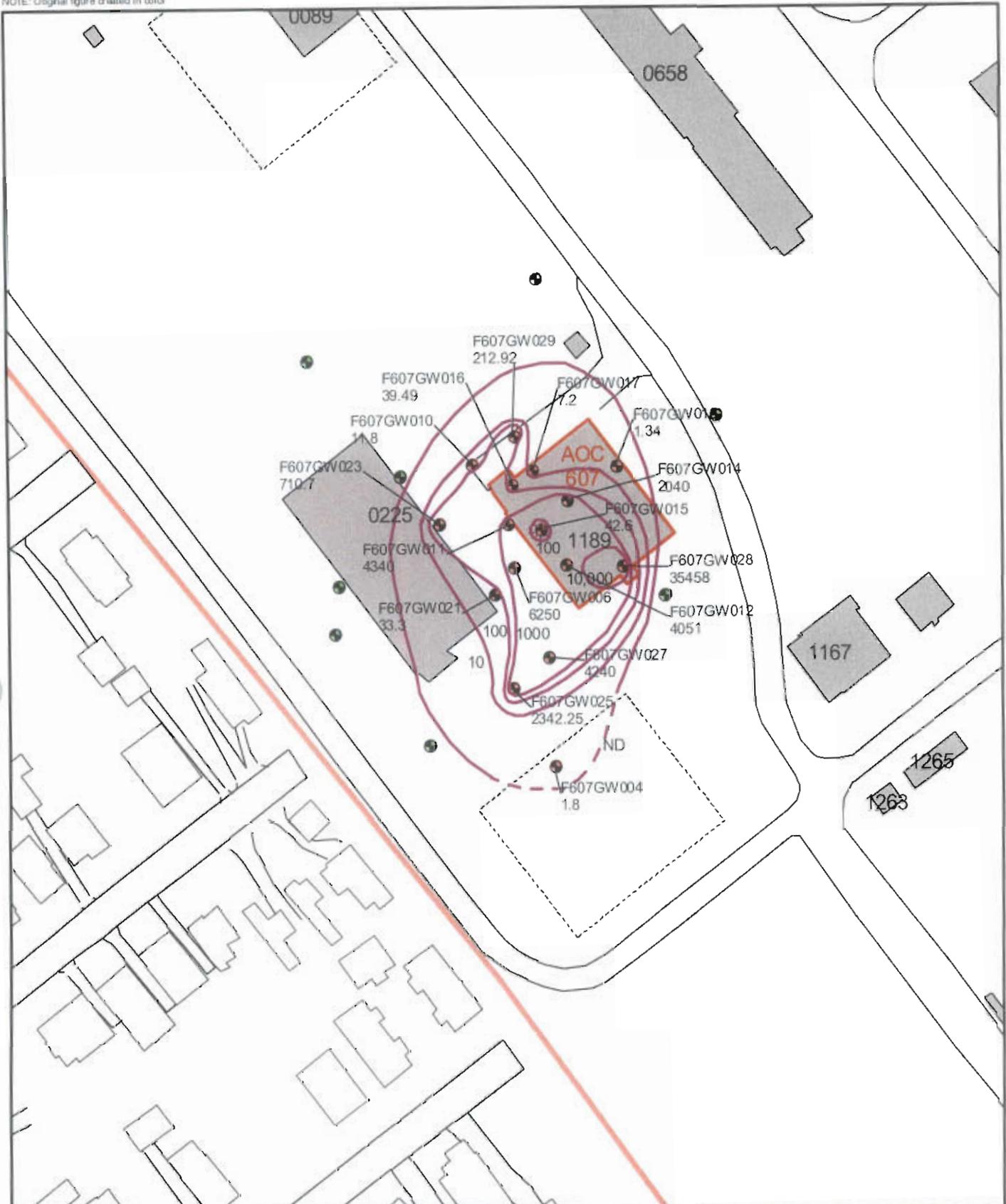


Figure 2-2
 IM Groundwater Monitoring Locations
 AOC 607, Zone F
 Charleston Naval Complex

Figure 2-4
PCE Distribution - 3-D Plan View
September 2001 and January 2003
AOC 607, Zone F
Charleston Naval Complex



NOTE: Original figure created in color



- Detect (Concentrations in ug/L)
- Non-Detect
- Known Isoconcentration Contour (ug/L)
- - - Inferred Isoconcentration Contour (ug/L)
- - - Fence
- Roads
- AOC Boundary
- Buildings
- Zone Boundary

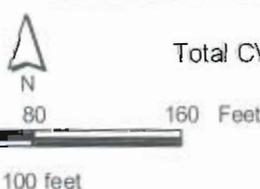
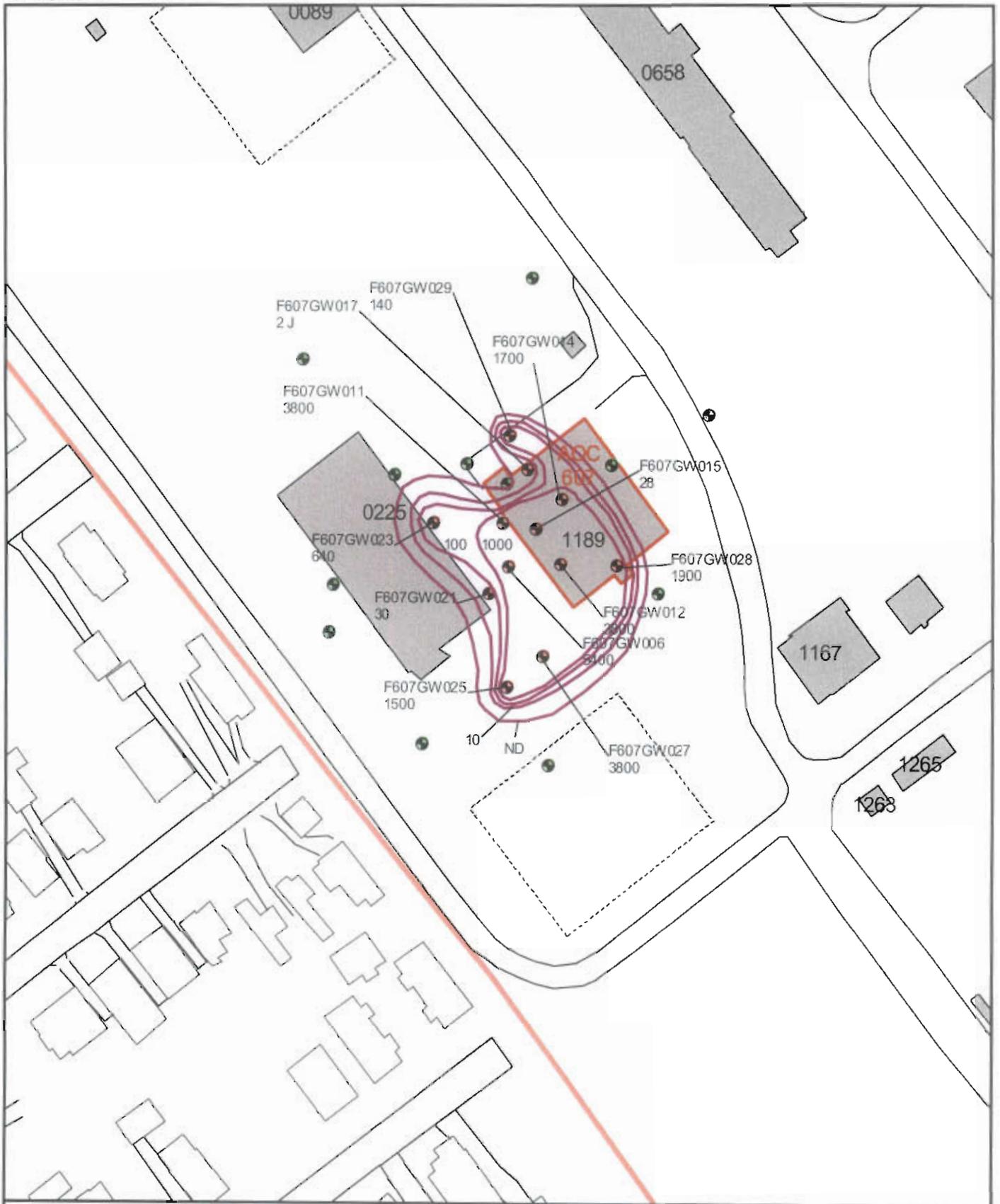


Figure 2-5
 Total CVOC Isoconcentration Contours - January 2003
 AOC 607, Zone F
 Charleston Naval Complex

CH2MHILL

NOTE: Original figure created in color



- Detect (Concentrations in ug/L)
- Non-Detect
- ~ Isoconcentration Contour (ug/L)
- Roads
- - - Fence
- ▭ AOC Boundary
- ▭ Buildings
- ▭ Zone Boundary

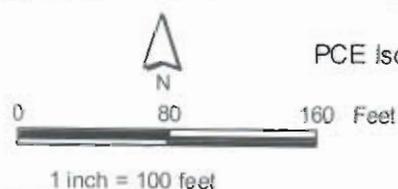


Figure 2-6
 PCE Isoconcentration Contours - January 2003
 AOC 607, Zone F
 Charleston Naval Complex

SECTION 3.0

**RAOs, Proposed MCSs, and Alternative
Evaluation Criteria**

3.0 RAOs, Proposed MCSs, and Alternative Evaluation Criteria

This section discusses the RAOs of this CMS and presents proposed MCSs for CVOCs in groundwater of the surficial aquifer. Once the RAOs and MCSs are established, candidate remedial technologies and alternatives can be developed to meet these objectives. This section also identifies the evaluation criteria used to compare the CMS alternatives.

3.1 Remedial Action Objectives

RAOs are medium-specific goals that protect human health and the environment by preventing or reducing exposures under current and future land use conditions. The RAOs for this site are to:

- Prevent migration of contamination of the COCs in groundwater into uncontaminated areas,
- Prevent unacceptable exposure of receptors to hazardous concentrations of COCs in groundwater, and
- Restore the beneficial uses of the aquifer to the extent practicable.

The attainment of the first two RAOs can be achieved using conventional technologies. Because the site groundwater is suspected of being contaminated with a chlorinated solvent DNAPL, the attainment of the third RAO may take many years. However, because of the removal of a significant amount of DNAPL from the site, dissolved phase groundwater concentrations are expected to decline in many areas of the site.

3.2 Remedial Goal Options and Proposed Media Cleanup Standards

Throughout the process of remediating a hazardous waste site, a risk manager uses a progression of increasingly acceptable site-specific media levels in considering remedial alternatives. RGOs and MCSs under RCRA are developed at the end of the risk assessment in the RFI/Remedial Investigation (RI)/state programs.

RGOs can be based on a variety of criteria, such as specific ILCRs (e.g., 1E-04, 1E-05, or 1E-06), HI levels (e.g., 0.1, 1.0, 3.0), or site background concentrations. For a particular RGO,

1 specific MCSs can be determined as target concentration values. These target MCSs are
2 estimated for industrial or residential (unrestricted) land use. It is also important to specify
3 the assumed land use and exposure conditions in the RGOs. Achieving these MCSs is
4 accepted as demonstrating that RGOs and RAOs have been achieved. Achieving these goals
5 result in the protection of human health and the environment, while achieving compliance
6 with applicable state and federal standards.

7 The exposure medium of concern for AOC 607 is CVOC-contaminated groundwater. The
8 specific chemicals for which RGOs and MCSs are needed include PCE, TCE, cis-1,2-DCE,
9 1,1-DCE, and vinyl chloride. The proposed MCSs for each of these chemicals are the current
10 drinking water maximum contaminant levels (MCLs). These values are presented in Table
11 3-1.

12 **3.3 Evaluation Criteria**

13 According to the RCRA permit issued by SCDHEC (SCDHEC, 1998), the alternatives were
14 evaluated with the following five criteria:

- 15 1. Protect human health and the environment.
- 16 2. Attain MCSs, which will generally be the RGOs.
- 17 3. Control the source of releases to minimize future releases that may pose a threat to
18 human health and the environment.
- 19 4. Comply with applicable standards for the management of wastes generated by remedial
20 activities.
- 21 5. Other factors include a) long-term reliability and effectiveness; b) reduction in toxicity,
22 mobility, or volume of wastes; c) short-term effectiveness; d) implementability; and e)
23 cost.

24 Each of the five criteria is defined in more detail below.

25 **3.3.1 Protect Human Health and the Environment**

26 The alternatives were evaluated on the basis of their ability to protect human health and the
27 environment. The ability of an alternative to achieve this criterion may or may not be
28 independent of its ability to achieve the other standards. For example, an alternative may be
29 protective of human health, but may not be able to attain the MCSs if the MCSs are not
30 directly tied to protecting human health.

1 **3.3.2 Attain MCSs**

2 The alternatives were evaluated on the basis of their ability to achieve the RGOs defined in
3 the *Interim Measure Completion Report/CMS Work Plan/Investigation Work Plan, AOC 607, Zone*
4 *F, Revision 0* (CH2M-Jones, 2003). Another aspect of this criterion is the time frame to
5 achieve the RGOs.

6 **3.3.3 Control the Source of Releases**

7 This standard deals with the control of releases of contamination from the source (the area
8 in which the contamination originated).

9 **3.3.4 Comply with Applicable Standards for Management of Wastes**

10 This criterion deals with the management of wastes derived from implementing the
11 alternatives; for example, treatment or disposal of well cuttings, contaminated groundwater,
12 or excavated material from a source area.

13 **3.3.5 Other Factors**

14 Five other factors are to be considered if an alternative is found to meet the four criteria
15 described above. These other factors are as follows:

16 **Long-term Reliability and Effectiveness**

17 The various alternatives will be evaluated on the basis of their reliability and the potential
18 impact should the alternative fail. In other words, a qualitative assessment was made as to
19 the chance of the alternative's failing and the consequences of that failure.

20 **Reduction in the Toxicity, Mobility, or Volume of Wastes**

21 Alternatives with technologies that reduce the toxicity, mobility, or volume of the
22 contamination were generally favored over those that do not. Consequently, a qualitative
23 assessment of this factor was performed for each alternative.

24 **Short-term Effectiveness**

25 Alternatives were evaluated on the basis of the risk they create during the implementation
26 of the remedy. Factors that may be considered include fire, explosion, and exposure of
27 workers to hazardous substances.

28 **Implementability**

29 The alternatives were evaluated for their implementability by considering any difficulties
30 associated with conducting the alternatives (such as the construction disturbances they may

1 create), operation of the alternatives, and the availability of equipment and resources to
2 implement the technologies comprising the alternatives.

3 **Cost**

4 A net present value of each alternative was developed. These cost estimates were used for
5 the relative evaluation of the alternatives, not to bid or budget the work. The estimates were
6 based on information available at the time of the CMS and on a conceptual design of the
7 alternative. They are "order-of-magnitude" estimates with a generally expected accuracy of
8 -30 percent to +50 percent for the scope of action described for each alternative. The
9 estimates were categorized into capital costs and operations and maintenance (O&M) costs
10 for each alternative.

TABLE 3-1
 Proposed MCSs for VOCs in Groundwater at AOC 607
Corrective Measures Study Report/Pilot Study Work Plan, AOC 607, Zone F, Charleston Naval Complex

Chemical	Proposed MCS (µg/L)
Tetrachloroethene (PCE)	5
Trichloroethene (TCE)	5
Cis-1,2-Dichloroethene (cis-1,2-DCE)	70
1,1-Dichloroethene (1,1-DCE)	7
Vinyl Chloride	2

µg/L Micrograms per liter

SECTION 4.0

**Description of Candidate Corrective
Measure Alternatives**

4.0 Description of Candidate Corrective Measure Alternatives

This section identifies and describes the candidate corrective measure alternatives for addressing the COCs in groundwater at AOC 607. The groundwater contamination area generally targeted in this CMS is shown on Figures 2-5 and 2-6 in Section 2.0 and includes both the shallow and deeper portions of the surficial aquifer where VOCs exceed the target MCSs.

Three RAOs were identified in Section 3.0. For each RAO, one or more technologies could be used to achieve the RAO. For example, for the RAO of preventing migration of contaminated groundwater, a variety of technologies could be used for this purpose, such as groundwater monitoring, groundwater recovery, or slurry walls. Similarly, for preventing unacceptable exposure of receptors to contaminants, land use controls (LUCs) that limit site activities or use of the aquifer for drinking water purposes can be applied. In order to develop an overall corrective measures approach that meets all three RAOs, various technologies capable of meeting the individual RAOs will first be considered and then an appropriate combination of technologies that meets all of the RAOs will be developed and proposed for implementation.

4.1 Candidate Approaches for Preventing Contaminated Groundwater Migration

Preventing the VOC-impacted groundwater from migrating into uncontaminated areas, particularly off site of the CNC, is an important RAO. While some limited downgradient migration of a VOC plume is often acceptable as part of a monitored natural attenuation remedial approach (provided that no unacceptable exposures occur and the plume is degrading), it is important that the VOC plume at AOC 607 does not migrate significantly from its current location or off site. All alternatives considered as a final remedy for this site will consider potential plume migration as part of the remedy selection and implementation process.

To date, significant migration of the plume away from the dry cleaner has not occurred. The most distal portion of the plume is less than approximately 200 feet from the dry cleaner.

The migration has been limited for several reasons, including slow groundwater velocities

1 at the site, on the order of 5 ft per year or less, and in part, due to apparent infiltration of
2 shallow groundwater into a sanitary sewer line that runs along side the dry cleaner through
3 the parking lot of Building 225. The groundwater potentiometric map for the site (see
4 Figure 3-1) shows a generally inward radial flow towards the sewer lines in this area of the
5 site. Although such inward flow can occur due to natural conditions, such as downward
6 flow into a lower aquifer unit, the data at AOC 607 suggest that the shallow groundwater is
7 likely slowly discharging into the sanitary sewer.

8 In order to assess whether VOC-impacted groundwater was infiltrating into the sanitary
9 sewer, four water samples were collected from the sewer at the locations shown in Figure
10 4-1. VOC concentrations detected in these samples are shown in Table 4-1. These data
11 indicate that some groundwater at the site is likely infiltrating into the sanitary sewer and
12 that the VOCs rapidly dissipate from the water. These concentrations are also expected to
13 decrease over time as remediation of the groundwater at the site proceeds.

14 The RDA may implement repairs to the sanitary sewer line in this area at some time in the
15 future. Consequently, alternatives that can be implemented to continue to limit the
16 migration of the plume after this sewer line is repaired are considered as part of this CMS.

17 Leading candidate alternatives for preventing migration of contaminated groundwater
18 include:

- 19 • Hydraulic Containment (e.g., groundwater recovery, treatment, and disposal).
- 20 • Physical Containment (e.g., impermeable barriers such as a slurry wall).

21 In addition to these approaches, groundwater monitoring of perimeter wells is an ancillary
22 technology that will be used to ensure that the selected containment approach is effective.

23 The two leading candidate containment technologies are described in more detail below.

24 **4.1.1 Hydraulic Containment**

25 **Technology Description**

26 Hydraulic containment systems are often referred to as “pump and treat” systems. While
27 these two terms are sometimes used interchangeably, the objective of hydraulic containment
28 is specifically to contain a plume and prevent its migration to downgradient locations. The
29 key elements of a hydraulic containment system typically include a groundwater recovery
30 system, treatment facilities (if necessary), and a groundwater disposal or discharge location.

31 The groundwater recovery system removes contaminated groundwater from the affected
32 aquifer and creates the necessary hydraulic gradients that prevent contaminated

1 groundwater from migrating away from the groundwater collection area. Groundwater
2 recovery can be achieved using vertical wells, collection trenches, or horizontal wells.
3 Because the size of the affected aquifer at AOC 607 is relatively small (less than 200 ft by 200
4 ft) and groundwater to be recovered is shallow, a groundwater recovery system using
5 conventional vertical recovery wells would likely be adequate for AOC 607.

6 Groundwater treatment methods depend on the type of contaminant and required level of
7 treatment for the selected groundwater disposal alternative. For AOC 607, the most likely
8 treatment method would be an air stripper to remove VOCs from groundwater.

9 Potential treated groundwater disposal methods include discharge to the sanitary sewer,
10 discharge to surface water (via an National Pollutant Discharge Elimination System
11 [NPDES] permit), or reinjection into the aquifer. Based on past experience at these types of
12 site, the most practicable disposal alternative would be to discharge to the sanitary sewer.

13 Hydraulic containment alone is not expected to be adequate to restore the aquifer to its
14 original unimpacted condition in the short term. However, because much of the PCE
15 DNAPL has been removed from the shallow aquifer, the groundwater concentrations of
16 VOCs are likely to decline over time in at least some portions of the affected area, as clean
17 groundwater from outside the contaminated area sweeps through the area.

18 **Key Uncertainties**

19 No significant uncertainties exist that are considered likely to limit the potential
20 effectiveness of hydraulic containment at AOC 607. Hydraulic containment systems are
21 commonly used and such an approach could be implemented at AOC 607 using
22 conventional technology. The specific number and optimal locations for recovery wells and
23 expected pumping rates are not currently known. However, these could be estimated using
24 a simple one-layer groundwater flow model, such as MODFLOW. Because the affected
25 aquifer is small, it is likely that a hydraulic containment system consisting of a few recovery
26 wells, small package groundwater treatment system (air stripper), and a discharge line to
27 the sanitary sewer would be all that is required for the site. A pump test may be needed as
28 part of the final design.

29 **4.1.2 Physical Containment**

30 **Technology Description**

31 Physical containment can be achieved using a variety of impermeable barriers. Commonly
32 used barriers for containing contaminated groundwater plumes include slurry walls and

1 sheet piling. These barriers prevent contaminated groundwater from migrating further by
2 cutting off the migration flow paths in the aquifer. Typically these barriers are installed
3 vertically into the aquifer around the area in which containment is desired. In some cases
4 the barrier is installed completely around the contamination plume; in other cases it may
5 only need to be installed partially around the plume. Importantly, the bottom of the barrier
6 must be installed into an aquitard underlying the area of containment. If an aquitard is not
7 present, contaminated groundwater may flow beneath the barrier.

8 For AOC 607, the clay layer that is present at approximately 11 ft below land surface
9 appears to be an adequate aquitard into which a containment barrier could be installed, thus
10 this approach is technically feasible from a hydrogeologic perspective. Also, the depth to
11 which the barrier must be installed (slightly greater than 11 ft) is relatively shallow, which
12 would significantly lower the cost for constructing a physical containment barrier.

13 The most significant limitation for this approach at AOC 607 is the presence of extensive
14 underground utilities throughout the site. Installation of a containment barrier in locations
15 where these underground utilities exist would be difficult and require more expensive
16 construction methods.

17 **Key Uncertainties**

18 The key uncertainties regarding this alternative relate to the viability of installing a barrier
19 across the many underground utilities that occur at the site. These utilities include sanitary
20 sewer lines, storm sewer lines, a potable water supply line, and possibly, an abandoned gas
21 line. Although the presence of these utilities does not render this alternative completely
22 infeasible, it increases the level of effort needed for implementation.

23 **4.1.3 Selection of Presumptive Approach for Preventing Contaminated** 24 **Groundwater Migration**

25 Based on the evaluation above, the presumptive approach for preventing contaminated
26 groundwater migration would be hydraulic containment. A hydraulic containment system
27 can be easily implemented. The presence of extensive underground utilities at AOC 607
28 raises significant questions as to the implementability of a physical containment approach.

29 **4.2 Candidate Approaches for Preventing Unacceptable** 30 **Exposures to Receptors**

31 The most viable approach to preventing unacceptable exposures of receptors to site COCs
32 during the corrective measures period is via implementation of LUCs. A variety of LUCs are

1 being implemented at the CNC, including restrictions on type of use (non-residential only),
2 groundwater use restrictions, and digging restrictions. These LUCs could be effectively
3 applied at AOC 607 and achieve the objective of preventing unacceptable exposure to
4 receptors. Few other methods are available that would be as effective as LUCs for achieving
5 this objective. For this reason, LUCs are selected as the presumptive approach for
6 preventing unacceptable exposure of COCs to receptors at the site.

7 **4.3 Candidate Approaches to Achieving Lower COC** 8 **Concentrations in Site Groundwater**

9 Currently available groundwater remedial technologies were screened for applicability to
10 contaminants and physical conditions present at AOC 607, with only viable remedial
11 technologies known for effective treatment of CVOCs in groundwater selected for achieving
12 this objective. These corrective measure technologies were selected due to their potential to
13 effectively reduce concentrations of VOCs in groundwater at AOC 607.

- 14 • Enhanced Reductive Dechlorination (ERD)
- 15 • In Situ Chemical Oxidation (ISCO)
- 16 • Monitored Natural Attenuation (MNA)

17 Detailed analyses of these technologies provide the rationale for selecting the recommended
18 corrective measure alternative.

19 **4.3.1 Enhanced Reductive Dechlorination**

20 **Technology Description**

21 CVOCs have been shown to be biodegradable, primarily under anaerobic condition. The
22 main CVOC biodegradation mechanism in anaerobic environments is reductive
23 dechlorination, which involves the sequential replacement of chlorine atoms on the alkene
24 molecule by hydrogen atoms.

25 In anaerobic reductive dechlorination, a carbon atom in the chlorinated solvent accepts an
26 electron from an electron donor (reduction), causing the release of a chlorine atom
27 (dechlorination). The more chlorine atoms a compound has, the more oxidized its carbon is,
28 and therefore the more susceptible it is to reductive dechlorination. This results in
29 sequential dechlorination of a contaminant. The general reductive dechlorination process
30 results in the formation of breakdown products as detailed below:

31 $\text{PCE} \Rightarrow \text{TCE} \Rightarrow \text{DCE} \Rightarrow \text{vinyl chloride} \Rightarrow \text{ethene}$

1 The chlorinated ethenes serve as electron acceptors in these degradation reactions. This
2 process is referred to as dehalorespiration. Organic carbon compounds such as sugars,
3 alcohols, and fatty acids serve as electron donors. This natural process is occurring to some
4 extent at AOC 607, as evidenced by the large amount of cis-1,2-DCE detected since
5 completion of the ERH activities. Enhanced reductive dechlorination would involve
6 implementing more active measures in areas of elevated PCE concentration to accelerate the
7 naturally occurring process.

8 The dechlorination process is effective for dissolved-phase CVOCs and may have some
9 success with DNAPL-level concentrations of chlorinated solvents.

10 For anaerobic biodegradation to be successful, adequate quantities of electron donors,
11 electron acceptors, and nutrients must come in contact with the active microbial consortia
12 and the target contaminants. Not all natural groundwater systems have the essential
13 microbiological organisms needed to achieved complete reductive dechlorination of PCE
14 and TCE to ethene. One group of bacteria, *Dehalococcoides ethenogenes*, has been found to be
15 capable of complete dechlorination. At some sites, addition of a microbiological consortium
16 containing *Dehalococcoides ethenogenes* may be an alternative to improve the degree of
17 reductive dechlorination achieved.

18 Hydrogen is the electron donor used by *Dehalococcoides ethenogenes* and other micro-
19 organisms in dehalorespiration. The hydrogen is released by the anaerobic fermentation of
20 organic carbon. Other microbes, such as methanogens, compete with dehalorespiring
21 bacteria for available hydrogen.

22 A commonly used approach for achieving enhanced reductive dechlorination is
23 biostimulation - which is providing a fermentable substance into the groundwater.
24 Commonly used substrates include Hydrogen Release Compound® (a proprietary lactate
25 polymer), molasses, lactate, and other readily biodegradable materials. Indigenous
26 anaerobic microorganisms ferment these organic chemicals, resulting in the release of
27 hydrogen. The hydrogen can then be used by organisms capable of dechlorinating CVOCs.
28 However, not all substrates are equally effective at all sites. At some sites a particular
29 substrate may be effective at allowing the microbes to achieve enhanced or complete
30 dechlorination, while at other sites that same substrate may not be as effective. Thus,
31 identifying an appropriate substrate is an important element of this process.

32 The addition of a substrate or other enhancements can be achieved through injection in
33 conventional wells or by inserting the material(s) directly into the aquifer using direct-push

1 technologies. The effectiveness of any enhancement or anaerobic reductive dechlorination is
2 dependent on the ability to supply the rate-limiting reagent directly to the microorganisms
3 and the presence of the appropriate microbes and hydrogeologic conditions.

4 At some sites, the activity of naturally occurring microorganisms is significantly reduced or
5 potentially inhibited because of site geochemical conditions. Bioaugmentation may also be
6 applicable if the appropriate bacteria are not present. Bioaugmentation involves the
7 injection of a known microbial consortia of chlorinated solvent-degrading bacteria. At some
8 sites, conversion of PCE to cis-1,2-DCE occurs, but further degradation does not occur, even
9 after the addition of electron donors and nutrients. Implementation of bioaugmentation
10 with selected known chlorinated solvent-degrading consortia known to be capable of
11 completing dechlorination to ethene (Major et al., 2001) has been found to be effective at
12 some sites. Complete dechlorination has occurred at these sites when bioaugmentation with
13 microbial cultures known to be capable of complete dechlorination has been employed.
14 Bioaugmentation is considered potentially applicable in these special cases and can be
15 evaluated through laboratory microcosm study or pilot testing.

16 **Key Uncertainties**

17 Key uncertainties for implementing ERD at AOC 607 include identification of an effective
18 substrate that maximizes the degree of reductive dechlorination achieved and whether the
19 natural bacterial consortium present at the site can achieve complete reductive
20 dechlorination.

21 **4.3.2 In Situ Chemical Oxidation**

22 **Technology Description**

23 Oxidative treatment is advantageous as a remedial technology for chlorinated ethenes
24 because it is rapid and aggressive. In situ oxidation is achieved by delivering chemical
25 oxidants to contaminated media, resulting in the contaminants being completely oxidized
26 into carbon dioxide (CO₂) or converted into innocuous compounds (such as chloride)
27 commonly found in the subsurface. The most widely used oxidants include hydrogen
28 peroxide (Fenton's reagent), potassium permanganate, sodium permanganate, and ozone.
29 Permanganate is less sensitive to pH effects than hydrogen peroxide or ozone. While
30 optimum performance occurs at a near neutral pH, permanganate oxidation is effective
31 from pH 3 to pH 12 (Siegrist, 2000). Primarily because of its greater stability, permanganate
32 is the best oxidant for application at AOC 607.

1 The subsurface injection of potassium permanganate (KMnO₄) solution can be used to
2 achieve the in situ destruction of organic compounds, including chlorinated ethenes such as
3 TCE, PCE, and toluene. The balanced chemical equation for oxidation of PCE (C₂Cl₄) by
4 KMnO₄ is as follows:



6 Based on this stoichiometry, 1.3 grams (g) of KMnO₄ is needed to mineralize 1 g of TCE; 1 g
7 of KMnO₄ produces approximately 0.55 g of MnO₂ solids.

8 KMnO₄ is a non-selective oxidizing agent and may also be consumed by natural organic
9 matter (NOM) and other oxidizable species present in soil and groundwater (such as PCE).
10 In fact, in the absence of very high levels of PCE in soil, such as residual non-aqueous phase
11 liquid (NAPL), KMnO₄ demand due to non-target compounds such as NOM is often greater
12 than the contaminant demand. The soil oxidant demand of the native soils is commonly
13 denoted as soil oxidant demand (SOD), with units of g KMnO₄ per kilogram (kg) of soil.

14 KMnO₄ dosages reported in technical literature range from approximately 0.1 to 20 g
15 KMnO₄ per kg of soil (Clayton et al, 2000; Lowe et al, 2002; and Siegrist et al., 2001). As
16 described above, in most cases the oxidant dosage is controlled by the native soil SOD, as
17 opposed to the contaminant concentrations. Furthermore, KMnO₄ reaction can limit the
18 effective radius of treatment around an injection point, if the KMnO₄ dose delivered is less
19 than the applicable SOD value.

20 Oxidant consumption proceeds until the applied oxidant dosage is depleted or until
21 oxidizable material is completely reacted. At high oxidant dosages (i.e., greater than the
22 ultimate oxidant demand) the oxidant may not be fully consumed. Furthermore, the
23 ultimate oxidant demand and reaction rates will vary according to the applied KMnO₄
24 dosage, with higher KMnO₄ concentrations leading to faster reaction rates and higher
25 ultimate SOD values.

26 **Key Uncertainties**

27 Key uncertainties for this technology include the amount of natural oxidant demand
28 available in site soils. A high oxidant demand decreases treatment efficiency of the oxidant
29 and requires significantly greater quantities of oxidants, which increases costs. Also, based
30 on the results of other ISCO projects at the CNC, the degree to which rebound of
31 contamination will occur after the oxidant has been consumed is uncertain. For
32 permanganate, and additional uncertainty is the degree to which manganese dioxide, which

1 forms upon reduction of the permanganate, may occur and whether its accumulation could
2 lead to a reduction of the hydraulic conductivity of the aquifer.

3 **4.3.3 Monitoring/Natural Attenuation**

4 **Technology Description**

5 Natural attenuation is the reduction of CVOC concentration by the natural processes
6 present in the aquifer, including volatilization, hydrolysis, dilution, dispersion, adsorption,
7 and biotic and abiotic degradation. The collective effect of these processes is termed natural
8 attenuation. MNA is a careful evaluation of natural attenuation mechanisms using
9 monitoring. EPA has issued a Draft Final OSWER Directive on Monitored Natural
10 Attenuation (EPA, 1997), in which it recognizes that MNA is appropriate as a remedial
11 approach, "where it can be demonstrated capable of achieving a site's remedial objectives
12 within a time frame that is reasonable compared to that offered by other methods, and
13 where it meets the applicable remedy selection criteria for that particular OSWER program."
14 EPA clearly states its expectation that "monitored natural attenuation will be most
15 appropriate when used in conjunction with active remediation measures (e.g., source
16 control) or as a follow-up to active remediation measures that already have been
17 implemented."

18 Under the MNA alternative, the CVOC plume would be evaluated using a monitoring
19 system designed to track the plume location and magnitude. Monitoring data would be
20 compared to the predicted transport and fate of the CVOCs to check prediction accuracy.

21 In general, the MNA alternative consists of three major features:

- 22 • A designed monitoring program,
- 23 • A tracking and data evaluation program, and
- 24 • A contingency response plan in the event that the monitoring indicates downgradient
25 migration of dissolved CVOCs.

26 The MNA alternative would be implemented in conjunction with a long-term monitoring
27 plan. The purpose of the plan is to monitor plume migration over time and to verify that
28 natural attenuation is occurring. The plan would specify monitoring existing wells located
29 within, upgradient to, crossgradient to, and downgradient of the dissolved-phase plume.

30 The monitoring plan may include CVOCs, dissolved oxygen (DO), nitrates, ferrous iron,
31 sulfates, common cations and anions, and dissolved hydrocarbon gases, ethene, ethane, and

1 methane. The data would provide characterization of plume extent, native groundwater
2 quality, oxygen reduction potential (ORP) indicators, and indicators of biological
3 degradation products of the CVOCs.

4 Recent developments in the study of MNA have made it easier to evaluate the potential
5 success of an MNA alternative. One of these developments includes the analysis for
6 *Dehalococcoides ethenogenes*. A variety of halo-respiring bacteria have been shown to
7 dechlorinate PCE and TCE to cis-1,2-DCE, but only *Dehalococcoides ethenogenes* has been
8 documented to cause the complete dechlorination of PCE and TCE to ethene (Hendrickson,
9 2002). DNA molecular tools are used to provide semi-quantitative population density data
10 on this microorganism. The advantage of detecting *Dehalococcoides* is that its presence has
11 been correlated with complete dechlorination.

12 **Key Uncertainties**

13 Key uncertainties for MNA at AOC 607 include whether there is sufficient naturally
14 occurring organic material in the aquifer to provide adequate substrate for biological
15 degradation and whether the native bacterial consortium are adequate to achieve complete
16 dechlorination.

TABLE 4-1
VOC Results for Sanitary Sewer Sampling At AOC 607; March 2004
*Corrective Measures Study Report/Pilot Study Work Plan, AOC 607, Zone F,
Charleston Naval Complex*

Chemical	Station 1	Station 2	Station 3	Station 4
PCE	108	878	115	19
TCE	70	732	92	15
cis-1,2 DCE	105	1420	186	33
Vinyl Chloride	10	53	5	10 U

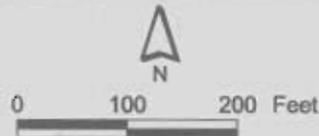
All results in micrograms per liter ($\mu\text{g/L}$).

U Analyte was not detected.

NOTE: Aerial Photo Date is 1997
NOTE: Original figure created in color



▲ Surface Water



1 inch = 169.736 feet

Figure 4-1
Sanitary Sewer Sampling Locations
Zone F; AOC 607
Charleston Naval Complex

SECTION 5.0

Detailed Analysis of Alternatives

1 **5.0 Detailed Analysis of Alternatives**

2 This section presents the detailed analyses of the corrective measure alternatives for
3 reducing groundwater concentrations of VOCs in the shallow interval of the surficial
4 aquifer at AOC 607. These alternatives include enhanced in situ anaerobic biodegradation,
5 ISCO, and MNA, which are described in Section 4.0. In this section, these alternatives are
6 evaluated using the criteria described in Section 3.3 and presented in Table 5-1.

7 It is expected that the overall set of corrective measures implemented at AOC 607 will
8 include hydraulic containment, LUCs, and one of the technologies described in this section.

9 **5.1 Enhanced Reductive Dechlorination**

10 Application of enhanced reductive dechlorination would involve injection of an appropriate
11 electron donor into the surficial aquifer and monitoring of the groundwater to determine the
12 degree to which reductive dechlorination becomes enhanced. For the purpose of evaluating
13 this alternative, it is assumed that one of the more widely effective substrates, such as
14 lactate, would be a suitable electron donor and that it would be injected via conventional
15 wells. If necessary, the system could also be bioaugmented with a commercially available
16 bacterial consortium known to contain Dehalococcoides.

17 For this alternative, it is assumed that potassium lactate ($C_3H_5KO_3$) would be injected into
18 five existing shallow monitoring wells (F607GW006, F607GW011, F607GW012, F607GW027,
19 and F607GW028) in which the greatest VOC concentrations were recently measured at the
20 site and a new well installed near well F607GW018D. Groundwater would be monitored
21 downgradient of these wells to assess the effectiveness of this approach. Lactate was
22 selected as the presumed electron donor since it is an easily fermented substrate that has
23 been effectively used at many sites and is easy to inject. Lactate solutions are easily handled
24 and there is no health risk, since lactate exists naturally in the body and is used as a
25 flavoring salt for food. Approximately six additional monitoring wells screened in the
26 shallow interval of the surficial aquifer would be installed to evaluate performance. The
27 general locations of these wells are depicted in Figure 5-1.

28 Typically lactate can sustain fermentation for approximately 10 to 45 days once injected. The
29 length of time required between injections depends on a variety of site-specific factors. For
30 this application, it is assumed that eight injections of lactate will be performed annually.

1 Monitoring will be used to evaluate the impact on dissolved CVOC concentrations and the
2 distribution and fermentation effects of lactate following the initial injection. Information
3 obtained during the injection and performance monitoring period will be used to further
4 enhance the design of future injection events. Parameters monitored would include field
5 parameters (DO, oxidation-reduction potential, pH, and temperature), VOCs, volatile fatty
6 acids (VFAs), alkalinity, dissolved iron and related geochemical parameters.

7 It is expected that if this process is found to be effective, it would achieve a significant
8 amount of reduction in VOC concentrations over the first several years in which it is
9 implemented, with a declining amount of additional benefit in later years, once the portions
10 of the residual plume that is amenable to this technology have been effectively treated. For
11 this reason, an implementation period for the ERD process of up to 3 years has been
12 assumed. However, other elements of this alternative (hydraulic containment and LUCs)
13 would continue as long as necessary. Groundwater monitoring would also continue during
14 the period after implementation of ERD.

15 **5.1.1 Protection of Human Health and the Environment**

16 This alternative will be protective of human health and the environment, because the LUCs
17 that will be implemented as part of this alternative will preclude use of site groundwater for
18 potable purposes.

19 **5.1.2 Attainment of MCSs**

20 It is unlikely that, even under the best conditions and following ERH treatment for source
21 area reduction, treatment of the dissolved-phase CVOCs to below MCLs will be achieved in
22 the short and intermediate term in the remaining areas of the site with elevated VOCs. At
23 AOC 607 reduction of CVOCs in localized regions within the shallow interval of the surficial
24 aquifer would require greater than 95-percent reduction in concentration to meet their
25 respective MCLs. However, this alternative is expected to affect a significant reduction in
26 dissolved-phase VOC concentrations.

27 **5.1.3 Control of the Source of Releases**

28 The historical source of VOCs no longer exists at AOC 607. Some minor residual amounts of
29 DNAPL may still be present or some of the DNAPL may have become absorbed into the
30 clay matrix.

1 **5.1.4 Compliance with Applicable Waste Management Standards**

2 This approach will generate minimal waste during implementation, limited to solid waste
3 associated with well drilling and well development and purge water. Soil cuttings from
4 monitoring well installation will be sampled and analyzed for waste characterization
5 parameters prior to acceptance from a permitted facility. Liquid wastes will be disposed of
6 in accordance with applicable standards.

7 **5.1.5 Long-Term Reliability and Effectiveness**

8 If effectively applied, this approach has the potential for achieving long-term effectiveness.
9 However, as previously noted, it is expected to take decades to restore the aquifer to its
10 original unimpacted condition.

11 **5.1.6 Reduction of Toxicity, Mobility, or Volume of Wastes**

12 Biodegradation of the VOCs via ERD provides permanent destruction of the VOCs, thus
13 reducing the toxicity, mobility, and volume of the waste.

14 **5.1.7 Short-Term Effectiveness**

15 Through implementation of the LUCs, this alternative will be effective in the short term at
16 controlling exposure and reducing risk. As previously indicated, it may take some time
17 before significant reduction in VOC concentrations occur.

18 **5.1.8 Implementability**

19 This approach can be implemented with relatively low level of site disruption.

20 **5.1.9 Estimated Cost**

21 A summary of the estimated cost for this alternative is provided in Table 5-1. The summary
22 table presents the estimated capital and O&M costs, along with the calculated present worth
23 for each alternative. Detailed cost estimate tables are provided in Appendix A. The order-of-
24 magnitude level cost estimates are based on conceptual descriptions of the alternatives, not
25 detailed design information. These estimates have an expected accuracy of -30 percent to
26 +50 percent.

27 **5.2 In Situ Chemical Oxidation**

28 Application of ISCO using KMnO_4 would involve injection of the material into injection
29 wells in the vicinity of the existing monitoring wells (F607GW006, F607GW011, F607GW012,
30 F607GW027, F607GW028, and F607GW018D), as previously discussed in Section 4.2. A

1 conceptual design of an ISCO system would include the injection wells and up to six
2 additional monitoring wells screened in the surficial aquifer to evaluate performance. The
3 location of these proposed wells are depicted in Figure 5-1. The KMnO_4 application would
4 be conducted in two events separated by approximately 3 months of monitoring. This
5 approach will allow real-time evaluation of the injection response, and subsequent
6 adjustment of the injection plan for the second injection event.

7 The KMnO_4 solution used for injection would be mixed on site to obtain a concentration of 3
8 to 4 percent. Two separate mixing vessels would be used during the injection process to mix
9 and deliver solution in approximately 500-gallon batches. Based on the injection reaction to
10 the hydrogeological conditions at the site, it is estimated that approximately 14,000 gallons
11 of 3 percent KMnO_4 would be delivered during each injection event.

12 The design concentration of KMnO_4 and the volume of solution proposed for injection may
13 be changed prior to and/or during the injection event(s), based on SOD analyses and/or
14 other geologic factors encountered during the injection process. One soil sample from each
15 of the proposed new well locations would be collected and analyzed for SOD.

16 Parameters monitored after injection would include field parameters (DO, oxidation-
17 reduction potential, pH, and temperature), VOCs, permanganate, and manganese.

18 Based on previous experience with ISCO projects, after several injection events, subsequent
19 injections typically provide a diminishing level of treatment. For this reason, it is assumed
20 that only two injections would be conducted, separated by a 3-month monitoring period.
21 However, other elements of this alternative (hydraulic containment and LUCs) would
22 continue as long as necessary. Groundwater monitoring would also continue during the
23 period after implementation of ISCO.

24 **5.2.1 Protect Human Health and the Environment**

25 This alternative will be protective of human health and the environment, because the LUCs
26 that will be implemented as part of this alternative will preclude use of site groundwater for
27 potable purposes.

28 **5.2.2 Attainment of MCSs**

29 It is unlikely that, even under the best conditions and following ERH treatment for source
30 area reduction, treatment of the dissolved-phase CVOCs to below MCLs will be achieved in
31 the short and intermediate term in the remaining areas of the site with elevated VOCs. At
32 AOC 607 reduction of CVOCs in localized regions of the surficial aquifer would require

1 greater than 95-percent reduction in concentration to meet their respective MCLs. However,
2 this alternative is expected to affect a significant reduction in dissolved-phase VOC
3 concentrations.

4 **5.2.3 Control of the Source of Releases**

5 The historical source of VOCs no longer exists at AOC 607. Some minor residual amounts of
6 DNAPL may still be present or some of the DNAPL may have become absorbed into the
7 clay matrix.

8 **5.2.4 Compliance with Applicable Waste Management Standards**

9 This approach will generate minimal waste during implementation, limited to solid waste
10 associated with well drilling and well development and purge water. Soil cuttings from
11 monitoring well installation will be sampled and analyzed for waste characterization
12 parameters prior to acceptance from a permitted facility. Liquid wastes will be disposed of
13 in accordance with applicable standards.

14 **5.2.5 Long-Term Reliability and Effectiveness**

15 If effectively applied, this approach has the potential for achieving long-term effectiveness.
16 However, as previously noted, it is expected to take decades to restore the aquifer to its
17 original unimpacted condition.

18 **5.2.6 Reduction of Toxicity, Mobility, or Volume of Wastes**

19 Oxidation of the VOCs via ISCO provides permanent destruction of the VOCs, thus
20 reducing the toxicity, mobility, and volume of the waste.

21 **5.2.7 Short-Term Effectiveness**

22 Through implementation of the LUCs, this alternative will be effective in the short term at
23 controlling exposure and reducing risk. Because the oxidants work quickly, this approach
24 would be expected to demonstrate a reduction in VOC concentrations in the short term.

25 **5.2.8 Implementability**

26 This approach can be implemented with relatively low level of site disruption.

27 **5.2.9 Estimated Cost**

28 A summary of the estimated cost for this alternative is provided in Table 5-1. The summary
29 table presents the estimated capital and O&M costs, along with the calculated present worth
30 for each alternative. Detailed cost estimate tables are provided in Appendix A. The

1 order-of-magnitude level cost estimates are based on conceptual descriptions of the
2 alternatives, not detailed design information. These estimates have an expected accuracy of -
3 30 percent to +50 percent.

4 **5.3 Monitoring/Natural Attenuation**

5 MNA would consist of the periodic monitoring of key monitoring wells screened in the
6 shallow interval of the surficial aquifer at AOC 607 for VOCs and select MNA parameters.
7 The purpose of the MNA alternative is to monitor plume reduction over time and to verify
8 that natural attenuation is occurring. As a result of the ERH operation for PCE source area
9 reduction, it is expected that the dissolved CVOC plume in a large area of the site would
10 slowly decrease in concentration as a result of natural attenuation.

11 Monitoring would be conducted in the 12 wells located within the area treated via ERH.
12 Parameters measured would include field parameters (DO, oxidation-reduction potential,
13 pH, and temperature), VOCs, and various geochemical indicators (such as alkalinity and
14 dissolved iron). It is assumed that MNA monitoring would continue for up to 20 years.
15 Groundwater monitoring to ensure hydraulic containment would also continue during the
16 period after implementation of MNA.

17 **5.3.1 Protect Human Health and the Environment**

18 This alternative will be protective of human health and the environment, because the LUCs
19 that will be implemented as part of this alternative will preclude the use of site groundwater
20 for potable purposes.

21 **5.3.2 Attainment of MCSs**

22 It is unlikely that, even under the best conditions and following ERH treatment for source
23 area reduction, treatment of the dissolved-phase CVOCs to below MCLs will be achieved in
24 the short and intermediate term in the remaining areas of the site with elevated VOCs. At
25 AOC 607 reduction of CVOCs in localized regions of the surficial aquifer would require
26 greater than 95-percent reduction in concentration to meet their respective MCLs. This
27 alternative may achieve a significant reduction in dissolved-phase VOC concentrations over
28 time.

1 **5.3.3 Control of the Source of Releases**

2 The historical source of VOCs no longer exists at AOC 607. Some minor residual amounts of
3 DNAPL may still be present or some of the DNAPL may have become absorbed into the
4 clay matrix.

5 **5.3.4 Compliance with Applicable Waste Management Standards**

6 This approach will generate minimal waste during implementation, limited to well purge
7 water. Liquid wastes will be disposed of in accordance with applicable standards.

8 **5.3.5 Long-term Reliability and Effectiveness**

9 If effectively applied, this approach has the potential for achieving long-term effectiveness.
10 However, as previously noted, it is expected to take decades to restore the aquifer to its
11 original unimpacted condition.

12 **5.3.6 Reduction of Toxicity, Mobility, or Volume of Wastes**

13 Biodegradation of the VOCs via MNA provides permanent destruction of the VOCs, thus
14 reducing the toxicity, mobility, and volume of the waste.

15 **5.3.7 Short-Term Effectiveness**

16 Through implementation of the LUCs, this alternative will be effective in the short term at
17 controlling exposure and reducing risk. As previously indicated, it may take some time
18 before significant reduction in VOC concentrations occur.

19 **5.3.8 Implementability**

20 This approach can be implemented with no site disruption.

21 **5.3.9 Cost**

22 A summary of the estimated cost for this alternative is provided in Table 5-1. The summary
23 table presents the estimated capital and O&M costs, along with the calculated present worth
24 for each alternative. Detailed cost estimate tables are provided in Appendix A. The order-of-
25 magnitude level cost estimates are based on conceptual descriptions of the alternatives, not
26 detailed design information. These estimates have an expected accuracy of -30 percent to
27 +50 percent. A scope contingency (20 percent) is added to cover additional unexpected
28 sampling events and/or analysis during the 5-year O&M period.

TABLE 5-1
 Detailed Analysis of Source Control Corrective Measure Alternatives
 Corrective Measures Study Report/Pilot Study Work Plan, AOC 607, Zone F, Charleston Naval Complex

Evaluation Criteria	Alternative 1: Hydraulic Containment, LUCs, and Enhanced Reductive Dechlorination	Alternative 2: Hydraulic Containment, LUCs, and In situ Chemical Oxidation	Alternative 3: Hydraulic Containment, LUCs and Monitored Natural Attenuation
Protection Of Human Health and the Environment	Process will be protective of human health and the environment.	Process will be protective of human health and the environment.	Process will be protective of human health and the environment.
Attainment of Media Cleanup Standards	Alternative can potentially significantly reduce VOC concentrations at site; however, it is not expected to achieve MCSS throughout the entire plume.	Alternative can potentially significantly reduce VOC concentrations at site; however, it is not expected to achieve MCSS throughout the entire plume.	Alternative can potentially significantly reduce VOC concentrations at site; however, it is not expected to achieve MCSS throughout the entire plume.
Control of the Source of Release	Original source of the release is no longer present. Process will gradually reduce contaminant mass in the source area.	Original source of the release is no longer present. Process will gradually reduce contaminant mass in the source area.	Original source of the release is no longer present. Process will gradually reduce contaminant mass in areas of dissolved concentration.
Compliance with Applicable Waste Management Standards	Not expected to accumulate significant quantities of waste requiring management.	Not expected to accumulate significant quantities of waste requiring management.	Not expected to accumulate significant quantities of waste requiring management.
Long-Term Reliability and Effectiveness			
Magnitude of Residual Risk	Minimal residual risk due to LUCs, significant reduction of potential risk within areas of elevated VOC concentration in groundwater.	Minimal residual risk due to LUCs, significant reduction of potential risk within areas of elevated VOC concentration in groundwater	Minimal residual risk due to LUCs, gradual reduction of potential risk within areas of elevated VOC concentration in groundwater
Adequacy of Reliability of Controls	Expected to provide adequate control over the long term.	Expected to provide adequate control over the long term.	Expected to provide adequate control over the long term.
Reduction of Toxicity, Mobility, or Volume of Wastes			

TABLE 5-1
 Detailed Analysis of Source Control Corrective Measure Alternatives
 Corrective Measures Study Report/Pilot Study Work Plan, AOC 607, Zone F, Charleston Naval Complex

Evaluation Criteria	Alternative 1: Hydraulic Containment, LUCs, and Enhanced Reductive Dechlorination	Alternative 2: Hydraulic Containment, LUCs, and In situ Chemical Oxidation	Alternative 3: Hydraulic Containment, LUCs and Monitored Natural Attenuation
Amount of Hazardous Materials Anticipated to be Destroyed/Treated	If properly implemented, the alternative is expected to reduce volume and mass of CVOCs.	If properly implemented, the alternative is expected to reduce volume and mass of CVOCs.	If properly implemented, the alternative is expected to reduce volume and mass of CVOCs.
Degree and Quantity of Reduction	Moderate. Process is expected to reduce CVOC contaminant concentrations.	Moderate. Process is expected to reduce CVOC contaminant concentrations.	Low to moderate. Alternative has the long-term potential to decrease dissolved contaminant concentration.
Irreversibility of Reduction	High. Biodegradation of CVOCs from groundwater is irreversible.	High. Chemical oxidation is irreversible	High. Biodegradation of CVOCs via reductive dechlorination is irreversible.
Type and Quantity of Treatment Residuals	Minimal treatment residuals is anticipated.	Minimal treatment residuals is anticipated.	Minimal treatment residuals is anticipated.
Preference for Treatment as a Principal Element	Treatment is the principal component of this alternative.	Treatment is the principal component of this alternative.	Natural treatment is a component of this alternative.
Short-Term Effectiveness			
Protection of Workers During Remedial Action Construction	Implementation poses a minimal degree of safety and health hazards to workers. Requires a Site Health and Safety Plan.	Implementation poses a low degree of safety and health hazards to workers. Requires a Site Health and Safety Plan.	Implementation poses a low degree of safety and health hazards to workers. Requires a Site Health and Safety Plan.
Protection of Community During Remedial Action	Implementation poses a minimal degree of safety or health hazards to the CNC community.	Implementation poses a minimal degree of safety or health hazards to the CNC community.	Implementation poses a minimal degree of safety or health hazards to the CNC community.
(Short-Term Effectiveness)			
Environmental Impacts of Remedial Action	Process should not create adverse impacts on the environment.	Process should not create adverse impacts on the environment.	Process should not create adverse impacts on the environment.

TABLE 5-1
 Detailed Analysis of Source Control Corrective Measure Alternatives
 Corrective Measures Study Report/Pilot Study Work Plan, AOC 607, Zone F, Charleston Naval Complex

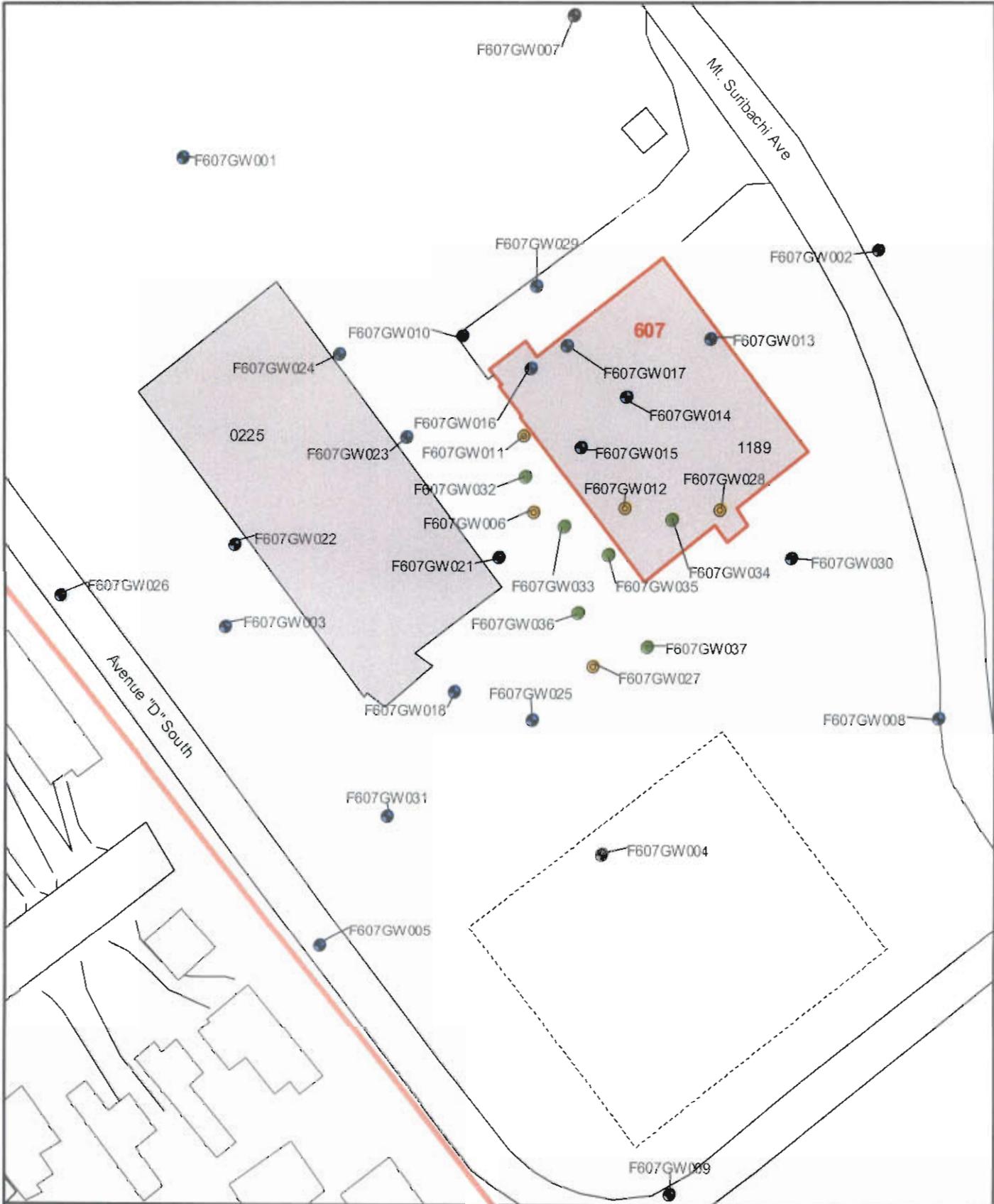
Evaluation Criteria	Alternative 1: Hydraulic Containment, LUCs, and Dechlorination	Alternative 2: Hydraulic Containment, LUCs, and In situ Chemical Oxidation	Alternative 3: Hydraulic Containment, LUCs and Monitored Natural Attenuation
Implementability			
Technical Feasibility	High. Except for the new innovative analytical techniques, process uses conventional and readily available technology.	High. Process uses conventional and readily available technology.	High. Except for the new innovative analytical techniques, process uses conventional and readily available technology.
Administrative Feasibility	High. Will require UIC permit. Pilot test will be required as part of the design process.	High. Will require UIC permit. Pilot test will be required as part of the design process.	High. Few major administrative issues are expected.
Estimated Costs^a			
Capital Cost	\$148,100	\$189,400	\$88,700
Annual O&M Cost	\$80,000 (Years 1-3) \$18,700 (Years 4-20)	\$76,000 (Year 1) \$17,700 (Years 2-20)	\$38,000 (Years 1-5) \$18,000 (Years 6-20)
Total Cost	\$490,000	\$464,000	\$410,000

^a Order-of-magnitude level cost estimates with expected accuracy of plus 50 to minus 30 percent.

^b Assumes 3.2 percent discount rate, 5-year operation period, and annual sampling for 20 years.

^c Assumes 3.2 percent discount rate and annual sampling for 20 years.

NOTE: Original figure created in color



- Existing Monitoring Well
- Injection Well
- Proposed Monitoring Well
- Fence
- Railroads
- Roads
- AOC Boundary
- SWMU Boundary
- Buildings
- Zone Boundary



Figure 5-1
 Conceptual Source Control Injection Plan
 AOC 607, Zone F
 Charleston Naval Complex

SECTION 6.0

**Recommended Corrective Measure
Alternative**

6.0 Recommended Corrective Measure Alternative

6.1 Recommended Alternative

Based on the preceding evaluation of available viable technologies and conditions at AOC 607, a corrective measure approach employing hydraulic containment, LUCs, and ERD (Alternative 1) is recommended as the preferred alternative. This alternative will meet all of the RAOs established for the site and reduce contaminant mass and volume in localized areas of the shallow interval of the surficial aquifer. The ERD process is relatively easy to implement and cost effective when compared to ISCO using KMnO_4 . It may provide for more substantial treatment of the residual plume compared to the other alternatives.

As noted in the technology description in Section 3.0, several uncertainties exist regarding implementation of the ERD process at AOC 607, including which substrate would maximize the degree of ERD achieved and whether the native microbiological consortium can achieve complete dechlorination of the PCE. These uncertainties can best be addressed via a pilot study.

A pilot study work plan for evaluating the effectiveness of ERD for this site is provided in Section 7.0 of this document.

6.2 General Contingency Plan

During the implementation of the recommended alternative or during the long-term monitoring phase expected to occur after remedy implementation has been completed, it is possible, although unlikely, that evidence of plume migration away from the contaminated area may be observed or that contaminant concentrations may begin to increase in one or more wells. In the event that plume migration appears to be occurring, the following contingent actions will be taken:

- Resampling of the wells will be implemented to confirm observed concentrations.
- The need for additional downgradient monitoring locations will be evaluated based on the available data.
- Appropriate downgradient samples will be collected and analyzed.

- 1 • An evaluation of the plume's stability and potential risks will be conducted.
- 2 • Appropriate actions, such as re-implementation of the selected remedy, will be
- 3 conducted to mitigate the contaminant migration.
- 4 In the event that VOC concentrations are observed to increase significantly in one or more
- 5 wells during the monitoring period, the following contingent actions will be taken:
- 6 • Resampling of the wells will be implemented to confirm observed concentrations.
- 7 • An evaluation of the plume's stability and potential risks will be conducted.
- 8 • Appropriate actions, such as re-implementation of the selected remedy, will be
- 9 conducted to mitigate the contaminant migration.
- 10 During any of these occurrences, communication with SCDHEC will be maintained to
- 11 ensure an appropriate and coordinated response.

SECTION 7.0

**Enhanced In Situ Anaerobic Biodegradation
Pilot Study Work Plan**

7.0 Enhanced In Situ Anaerobic Biodegradation Pilot Study Work Plan

7.1 Pilot Study Objectives and Goals

The purpose of the pilot study is to evaluate the viability of using ERD techniques to enhance the bioremediation of CVOCs in the shallow portion of the surficial aquifer at AOC 607. The primary goals of the pilot study are to:

- Assess the effectiveness of lactate as an organic substrate (electron donor) for the site;
- Assess the degree to which the naturally present bacterial consortium in the aquifer can effectively anaerobically degrade PCE; and
- Determine the required frequency of injection, necessary dosage of substrate, approximate radius of influence of the injection well, and overall substrate migration rate within the aquifer in this area.

This information will allow the overall viability and costs for full scale implementation to be better determined.

7.2 Pilot Study Approach

Key activities for the pilot study will include:

1. Baseline characterization (sampling and analysis) of microbiological and geochemical indicators and groundwater VOC concentrations, and
2. Implementation of substrate injection pilot test with post-injection monitoring.

Each of these key activities is described below.

7.2.1 Baseline Characterization Sampling and Analysis

Although the site has been well characterized for the purposes of the RFI and understanding the nature and extent of contamination, additional specific sampling will enhance the understanding regarding the amenability of the site to the ERD process, nature of the native microbiological consortium at the site, and current VOC concentrations. The proposed sampling and analysis includes groundwater analysis for VOCs, plus several recently developed analyses to assess the general nature of the native site bacteria.

1 Some recent studies have indicated that the presence of a unique bacteria species
2 (Dehalococcoides etheneogenes [DHE]) in the aquifer may indicate that the native bacterial
3 consortium at a site may be able to completely dechlorinate PCE to ethene. DHE is unique in
4 that it is an obligate dehalorespiring bacteria. It uses chlorinated ethene solvents exclusively
5 as its terminal electron acceptors and is one of the few bacteria identified that can
6 anaerobically dechlorinate DCE to vinyl chloride and then to ethene. Sampling and analysis
7 of site groundwater and aquifer material to assess the presence of DHE will be conducted
8 prior to implementation of the substrate injection pilot test. If naturally present in the
9 aquifer, DHE bacteria may allow for the complete anaerobic dechlorination of PCE without
10 requiring the addition of supplemental bacteria.

11 The presence of DHE bacteria can be detected using several DNA test methods developed in
12 recent years, such as the Polymerase Chain Reaction (PCR), whereby traces of DNA, specific
13 only to microbes of interest, are amplified from environmental samples such that they can
14 be identified. This approach does not allow for specific quantification of the existing and
15 present microbial population. However, a recently-developed analytical method (Real Time
16 PCR) allows for quantification of the number of microbes detected, as well as their
17 identification. CH2M-Jones proposes to perform Real Time PCR tests on groundwater and
18 soil samples as part of the baseline testing to assess the presence and number of DHE
19 organisms at AOC 607. This analysis is conducted commercially by only a few laboratories.
20 CH2M-Jones proposes to use Microbial Insights, Inc., in Knoxville, TN, for conducting this
21 analysis.

22 In addition to testing for DHE using Real Time PCR, CH2M-Jones proposes to conduct
23 analysis of soil and groundwater samples for phospholipid fatty acid (PLFA) content.
24 PLFAs are an important component in the metabolism of the cell. They degrade extremely
25 quickly once a bacteria dies. Analysis for PFLAs provide a quantitative means to measure
26 viable microbial biomass, overall bacterial community composition, and nutritional status.
27 The PFLA analysis provides significant information regarding the overall composition of
28 native bacterial consortium present in an aquifer. CH2M-Jones proposes to use Microbial
29 Insights for PFLA analysis.

30 In addition to the Real Time PCR and PFLA analyses, groundwater samples will be
31 collected from five existing wells (F607GW006, F607GW011, F607GW012, F607GW028, and
32 F607GW027) and analyzed for VOCs, field parameters (DO, ORP, temperature, pH,
33 conductance), sulfate/sulfide, dissolved iron and manganese, VFAs, and alkalinity. Table 7-
34 1 shows the proposed wells for sampling and parameters to be analyzed. Data from these

1 analyses will provide a baseline against which the effectiveness of the pilot test can be
2 compared.

3 **7.2.2 Substrate Injection Pilot Test and Post Injection Monitoring**

4 **Overview of Pilot Test Approach**

5 The overall approach to the pilot test will involve injection of a fermentable substrate into
6 the shallow aquifer via two wells located in the area of the site containing the highest levels
7 of VOCs. The response of the aquifer and groundwater quality will be measured
8 downgradient of the injection to assess changes in overall biological activity and degree of
9 biodegradation of the VOCs. New downgradient monitoring wells will be installed
10 approximately 10 ft downgradient of the injection locations.

11 Because native bacteria often require an acclimation period before they adjust to a change in
12 conditions, it may take between 3 to 6 months before the level of effectiveness of the
13 substrate injection can be adequately assessed. During this period, groundwater monitoring
14 will be performed to assess the response of aquifer to the injection of substrate. It is expected
15 that several injections of substrate will be required during this period to maintain or achieve
16 the desired reducing conditions.

17 **Target Treatment Area**

18 The area exhibiting the highest groundwater concentrations of CVOCs in the shallow
19 interval of the surficial aquifer includes monitoring wells F607GW006, F607GW011,
20 F607GW012, F607GW028, and F607GW027, as depicted in Figure 7-1. Wells F607GW027 and
21 F607GW028 have been selected for use as injection wells for the pilot test. Well F607GW028
22 has exhibited the greatest total VOC concentration during the most recent sampling, as well
23 as the greatest concentrations of cis-1,2-DCE. If the ERD process can be successfully
24 demonstrated at this location, it is likely that it can also be effectively applied across the rest
25 of the site as well. PCE concentrations in January in well F607GW027 were measured at
26 3,800 µg/L, making this well a good candidate for demonstrating whether this biotreatment
27 process can be effective.

28 **Monitoring Well Design**

29 New monitoring wells will be installed approximately 10 to 12 ft downgradient of well
30 F607GW027 and F607GW028. The monitoring wells will be constructed of 2-inch PVC
31 casing with 5 ft of 0.01 inch slotted well screen. The wells will be screened at the same
32 interval as the injections wells (from 6 to 11 ft bls for well F607GW027; from 8 to 13 ft bls for

1 well F607GW028). All standard well construction methods will be followed, per SCDHEC
2 requirements.

3 **Substrate Selection**

4 Because of its widespread success at many sites, lactate has been selected as the substrate to
5 be used to stimulate the reductive dechlorination for this pilot test. Lactate is a naturally
6 occurring organic compound often used in food as a preservative. There are no toxicity or
7 health risks associated with lactate.

8 Injection of lactate into the aquifer stimulates the ERD process because as it ferments, it
9 releases hydrogen gas, which is used as the electron donor by many bacteria, especially
10 those involved in the anaerobic biodegradation of chlorinated solvents, such as
11 Dehalococoides. Lactate typically first degrades to pyruvate, releasing a molecule of
12 hydrogen. Pyruvate then typically degrades to acetate, releasing another molecule of
13 hydrogen. Thus, one molecule of lactate can provide two molecules of hydrogen, which
14 then becomes available for dehalorepiring bacteria.

15 A solution of potassium lactate will be used for this pilot test. Potassium lactate was selected
16 over sodium lactate due to the significant amount of clay at AOC 607, since injection of high
17 sodium concentrations could cause swelling or other undesirable changes in the clay.
18 Potassium lactate is typically available as a 60 percent solution, shipped in standard 55-
19 gallon drums.

20 **Injection Process**

21 Prior to injection, the potassium lactate solution will be diluted with tap water to an
22 approximately 10 to 20 percent lactate solution. Approximately 200 gallons of this lactate
23 solution will be pumped into the well. A small, low pressure pump will be used to deliver
24 the lactate solution to the injection well. Following the lactate injection, approximately 20
25 gallons of clean water will be injected to flush the wells and push the lactate solution out
26 into the aquifer.

27 Based on the observed downgradient effects of the injection, the volume of lactate injected
28 during subsequent injections may be modified (increased upwards or downwards) to satisfy
29 the biological demand observed in the aquifer.

30 **7.2.3 Post-Injection Monitoring**

31 Monitoring will be performed on a monthly basis starting after the initial injection event.
32 After the first month, field parameters (DO, ORP, temperature, pH, conductance), VFAs,

1 and total organic carbon (TOC) will be measured in both pilot test monitoring wells to
2 assess the degree to which the aquifer quality is responding to the injection. After the
3 second month and continuing on through the target 6-month monitoring period, these
4 parameters, plus VOCs and additional parameters, will be analyzed. Table 7-2 provides the
5 post-injection monitoring schedule.

6 CVOCs, TOC, and VFAs are key parameters that will be used to evaluate the effectiveness
7 of the lactate injections. Dissolved gases will also be evaluated to assess dechlorination to
8 ethene and ethane, the availability of hydrogen, and the presence of methane. The presence
9 of methane demonstrates strong anaerobic conditions. The increase in biodegradation may
10 stimulate bacteria growth, thereby increasing the dissolved iron, manganese, and sulfide in
11 the groundwater. These parameters will be monitored during the period monitoring events,
12 every other month, starting 2 months after the initial injection.

13 Secondary performance monitoring events for parameters that can be measured with field
14 instruments will be completed monthly following the initial injection. In addition to the
15 VFA results, trends in decreasing TOC and increasing ORP levels will be used to schedule
16 additional lactate injections. DO and ORP results will also be used to evaluate the degree of
17 reducing conditions achieved in the aquifer.

18 Detected concentrations of DHE will be reviewed to assess whether DHE concentrations
19 appear to be increasing after the injection of lactate begins. If DHE concentrations are not
20 observed to increase within approximately 6 months after injection of lactate begins and
21 ethene is also not detected in groundwater samples, the injection of a commercially
22 available DHE-containing culture will be considered. If concentrations of DHE do not
23 appear to increase but ethane concentrations are increasing and complete biodegradation of
24 PCE occurs, it is likely that adequate DHE organisms are present and the addition of a
25 commercial DHE-containing culture is not required.

26 **Groundwater Monitoring Procedures**

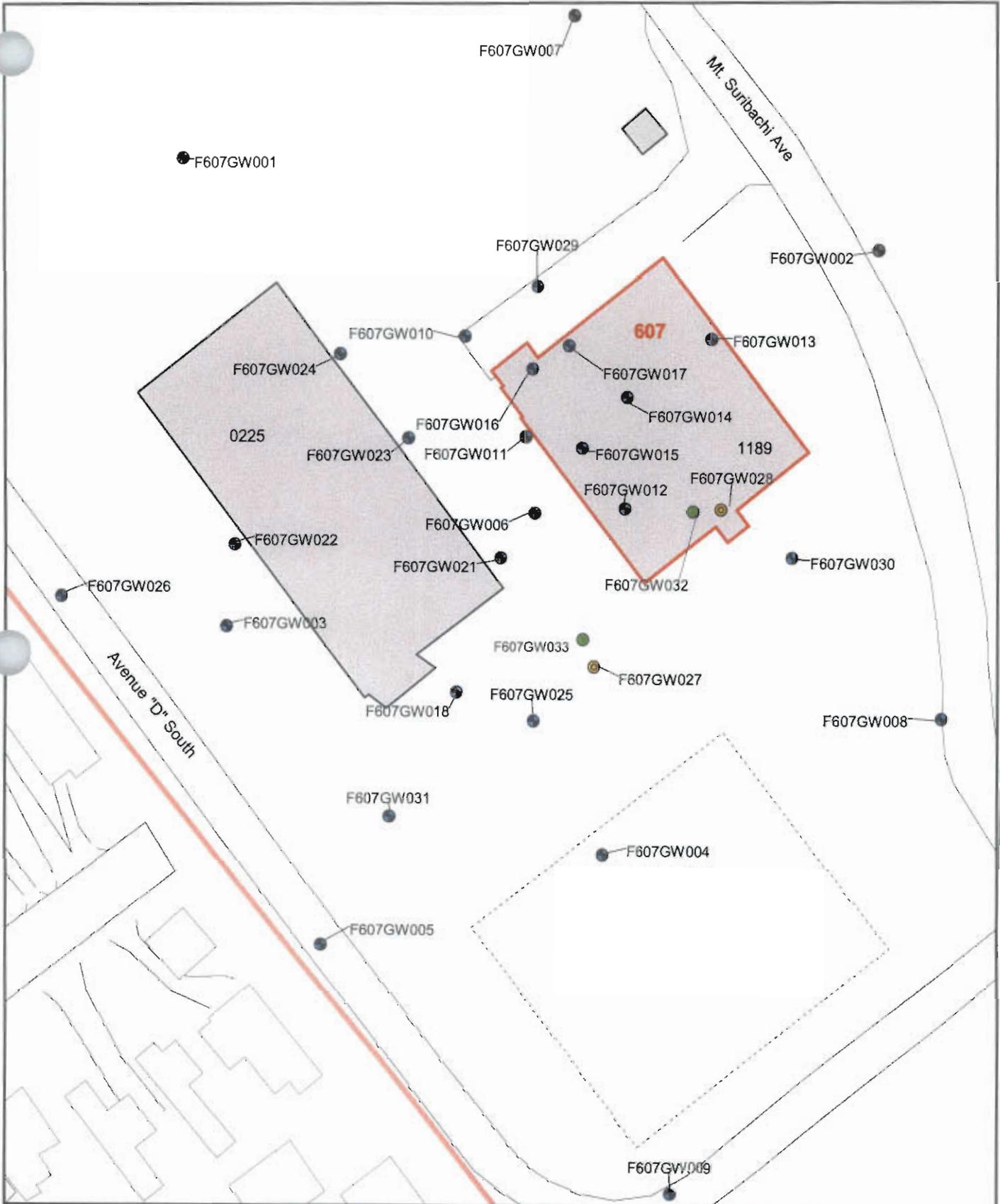
27 Groundwater monitoring will be completed using a low-flow groundwater sampling
28 technique to collect accurate field parameters (particularly DO and ORP) and less disturbed
29 groundwater samples for the evaluation of dissolved gases. The intake of the low-flow
30 pump will be placed in the middle of the screened interval and purging will continue until
31 the basic groundwater parameters stabilize (pH, temperature, and specific conductance) or
32 until the well has been purged for 30 minutes.

1 The groundwater analysis will follow the procedures found in the approved
2 Comprehensive Sampling and Analysis Plan (CSAP) portion of the RFI Work Plan (EnSafe,
3 Inc./Allen & Hoshall, 1994). The CSAP outlines all monitoring procedures to be performed
4 during the IM to characterize the environmental setting, source, and releases of hazardous
5 constituents. In addition, the CSAP includes the Quality Assurance Plan (QAP) and Data
6 Management Plan (DMP) to verify that all information and data are valid and properly
7 documented. Unless otherwise noted, the sampling strategy and procedures will be
8 performed in accordance with the EPA Environmental Services Division *Standard Operating*
9 *Procedures and Quality Assurance Manual (ESDSOPQAM)* (1996).

TABLE 7-2
 Post-Injection Monitoring for Wells F607GW032 and F607GW033
 Corrective Measures Study Report/Pilot Study Work Plan, AOC 607, Zone F, Charleston Naval Complex

Parameter	Method	Sample Volume, Container, and Preservative
Monthly Parameters (Months 1, 2, 3, 4, 5, and 6)		
DO, ORP, pH, temperature, and specific conductance	Field	Standard field instruments
VOCs	SW846-8260B	3-40 ml VOA vial (Teflon lined cap), pH <2 HCl, cool to 4°C
Methane, ethane, and ethene (MEE)	SW8015M	2-40 ml VOA vial (Teflon lined cap), pH <2 HCl, cool to 4°C
Volatile fatty acids (VFA)	Lab method	2-40 ml VOA vial (Teflon lined cap), cool to 4°C
Total Organic Carbon (TOC)	SW9060	250mL HDPE, pH <2 H2SO4, cool to 4°C
Bi-Monthly Parameters (Months 2, 4, and 6)		
All Monthly Parameters (see above)		
Sulfate	EPA 300.0	1L HDPE, cool to 4°C
Sulfide	EPA 376	1L HDPE, pH >9 NaOH, Zn Acetate, cool to 4°C
Dissolved iron (field filtered)	SW-846 6010B	250 or 500 mL in HDPE, preserved w/ HNO3 (pH < 2)
Dissolved manganese (field filtered)	SW-846 6010B	250 or 500 mL in HDPE, preserved w/ HNO3 (pH < 2)
Alkalinity	EPA 310.1	1L HDPE, cool to 4°C
DHE	Real-time PCR/Microbial Insights	1L poly (alcohol rinsed), cool to 4°C
PFLAs	/Microbial Insights	2 1L poly (alcohol rinsed) , cool to 4°C

NOTE: Original figure created in color



- Existing Monitoring Well
- Injection Well
- Proposed Monitoring Well
- Fence
- Railroads
- Roads

- ▭ AOC Boundary
- ▭ SWMU Boundary
- ▭ Buildings
- ▭ Zone Boundary

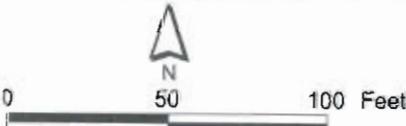


Figure 7-1
Enhanced In-Situ Anaerobic
Biodegradation Pilot Study Area
AOC 607, Zone F
Charleston Naval Complex

SECTION 8.0

References

1 8.0 References

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APPENDIX A

**Corrective Measure Alternative Detailed
Cost Estimates**

**COMPARISON OF TOTAL COST OF REMEDIAL SOLUTIONS
Source Control Alternatives**

Site: AOC 607
Location: CNC, Zone F

Base Year:
Date:

2004
10/01/03

	Alternative Number 1 Enhanced In Situ Anaerobic Biodegradation using $C_3H_5KO_3$ w/ Hydraulic Containment & LUCs	Alternative Number 2 In Situ Chemical Oxidation using $KMnO_4$ w/ Hydraulic Containment & LUCs	Alternative Number 3 Monitoring/ Natural Attenuation w/ Hydraulic Containment & LUCs
Total Project Duration (Years)	20	20	20
Capital Cost	\$148,100	\$189,400	\$88,700
Annual O&M Cost	\$80,000 (Year 1 - 3) \$18,700 (Year 4 - 20)	\$76,000 (Year 1) \$17,700 (Year 2 - 20)	\$38,000 (Year 1 - 5) \$18,000 (Year 6 - 20)
Total Present Worth of Solution	\$490,000	\$464,000	\$410,000
<p><small>Disclaimer The information in this cost estimate is based on the best available information regarding the anticipated scope of the remedial alternatives. Changes in the cost elements are likely to occur as a result of new information and data collected during the engineering design of the remedial alternative. This is an order-of-magnitude cost estimate that is expected to be within -30 to +50 percent of the actual project costs.</small></p>			

Alternative 1: Enhanced In Situ Anaerobic Biodegradation using C₃H₅KO₃ COST ESTIMATE SUMMARY

Site: Charleston Naval Complex **Description:** Potassium lactate injection in the shallow interval of the surficial aquifer.
Location: AOC 607
Phase: Corrective Measures Study
Base Year: 2004
Date: August 2003

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Baseline Groundwater Sample Collection Event	1	EA	\$5,300	\$5,300	Sample 6 Proposed Monitoring Wells
Monitoring Well Installation	1	EA	\$7,500	\$7,500	Six Shallow Wells @ 12 ft Deep
SUBTOTAL				\$12,800	
Potassium Latate Injection					Monthly injection events Assume 2000 gallons of lactate solution injected during each injection event.
Potassium Latate	600	LB	\$0.79	\$474	
Shipping - Potassium Latate	1	LS	\$200	\$200	600 pounds per drum
Equipment					
Lactate Mix System w/ one Tanks	1	EA	\$2,000	\$2,000	Two Injection Events
PPE	12	Event	\$25	\$300	Two weeks each
Generator	1	EA	\$500	\$500	
Decon Equipment/Waste Handling Materials	12	Event	\$75	\$900	
Steam Cleaner	12	Event	\$50	\$600	
Miscellaneous Materials/Supplies	12	Event	\$100	\$1,200	
Performance Monitoring					
C ₃ H ₅ KO ₃ Lab Sampling	3	EA	\$4,530	\$13,590	Sample 6 Proposed Monitoring Wells, quarterly for first year
C ₃ H ₅ KO ₃ Field Monitoring	9	EA	\$500	\$4,500	monthly for first year
Labor					
Labor - Site Superintendent	192	HR	\$40	\$7,680	2 Days per event
Labor - Field Engineer	192	HR	\$30	\$5,760	
Labor - Procurement Manager	20	HR	\$30	\$600	
SUBTOTAL - Injection and Monitoring				\$38,304	
Hydraulic Containment - Groundwater Extraction					
Land Use Controls	1	EA	\$52,100	\$52,100	
SUBTOTAL				\$5,000	
SUBTOTAL				\$108,204	
Project Management	5%	of	\$108,204	\$5,410	
Remedial Design	10%	of	\$108,204	\$10,820	
Construction Management	2%	of	\$108,204	\$2,164	
Subcontractor General Requirements	2%	of	\$108,204	\$2,164	
SUBTOTAL				\$12,758	
Contingency	15%	of	\$128,763	\$19,314	
TOTAL CAPITAL COST				\$148,100	

Site: Charleston Naval Complex **Description:** Potassium lactate injection in the shallow interval of the surficial aquifer.
Location: AOC 607
Phase: Corrective Measures Study
Base Year: 2004
Date: August 2003

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Potassium Latate Injection					
					Monthly Injections Assume 2000 gallons per injection event
Potassium Latate	600	LB	\$0.79	\$474	
Shipping - Potassium Latate	1	LS	\$200	\$200	600 pounds per drum
Equipment					
PPE	12	Event	\$25	\$300	Monthly Injections
Decon Equipment/Waste Handling Materials	12	Event	\$75	\$900	
Miscellaneous Materials/Supplies	12	Event	\$100	\$1,200	
Performance Monitoring					
C ₃ H ₅ KO ₃ Lab Sampling	3	EA	\$5,300	\$15,900	Sample 5 Existing and 6 Proposed Monitoring Wells
C ₃ H ₅ KO ₃ Field Monitoring	6	EA	\$500	\$3,000	
Labor					
Labor - Site Superintendent	192	HR	\$40	\$7,680	2 days per event
Labor - Field Engineer	192	HR	\$30	\$5,760	
Labor - Procurement Manager	20	HR	\$30	\$600	
SUBTOTAL - Injection and Monitoring				\$36,014	
Hydraulic Containment - Groundwater Extraction					
Land Use Controls	1	EA	\$12,000	\$12,000	
	1	EA	\$1,100	\$1,100	
Annual Report					
Labor - Project Manager	12	HR	\$125	\$1,500	
Labor - Engineer/Hydrogeologist	24	HR	\$90	\$2,160	
Labor - Editor	12	HR	\$65	\$780	
Labor - CAD Technician	12	HR	\$65	\$780	
SUBTOTAL - Annual Report				\$5,220	
TOTAL ANNUAL O&M COST				\$54,000	

PRESENT VALUE ANALYSIS

Discount Rate = 3.2%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	TOTAL PRESENT VALUE	NOTES
1	FIRST YEAR CAPITAL COST	\$148,100	\$148,100	\$148,100	
1-3	ANNUAL O&M COST (Year 1 - 3)	\$54,000	\$54,000	\$341,753	Annual Sampling Yrs 1-20 Assume 3 Yr Injection Plan - 12 Injections Per Year
4-20	ANNUAL O&M COST (Year 4 - 20)	\$18,800	\$18,800	\$489,853	Containment for 20 Years LUCs for 20 Years
TOTAL PRESENT WORTH OF ALTERNATIVE				\$490,000	

SOURCE INFORMATION

Alternative 2: **In-Situ Chemical Oxidation using KMnO4****COST ESTIMATE SUMMARY**

Site: Charleston Naval Complex
Location: AOC 607
Phase: Corrective Measures Study
Base Year: 2004
Date: August 2003

Description: Potassium permanganate injection in the shallow interval of the surficial aquifer.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Baseline Groundwater Sample Collection Event	1	EA	\$5,800	\$5,800	Sample 5 Existing and 6 Proposed Monitoring Wells
Monitoring Well Installation	1	EA	\$7,500	\$7,500	Six Shallow Wells @ 12 ft Deep
SUBTOTAL				\$13,300	
Potassium Permanganate Injection					Two injection events separated by 3 months Assume 14,000 gallons of 3% KMnO ₄ injected solution during each injection event. 3,142 pounds of KMnO ₄ per event or 6,284 pounds for the two events.
Potassium Permanganate	6,284	LB	\$1.35	\$8,483	
Shipping - Potassium Permanganate	1	LS	\$600	\$600	331 pounds per drum
Soil Oxidant Demand Analysis Equipment	6	EA	\$1,050	\$6,300	Aquifer Solutions Bid
KMnO ₄ Mix System w/ two 1,000 gal Tanks	1	EA	\$9,000	\$9,000	Two Injection Events Two weeks each
Drop Tube/Packer Assembly	1	EA	\$700	\$700	
PPE	2	Event	\$200	\$400	
Generator	1	EA	\$500	\$500	
Decon Equipment/Waste Handling Materials	2	Event	\$500	\$1,000	
Steam Cleaner	2	EA	\$200	\$400	
Miscellaneous Materials/Supplies	2	Event	\$500	\$1,000	
Performance Monitoring					
KMnO ₄ Lab Sampling	3	EA	\$5,800	\$17,400	Sample 5 Existing and 6 Proposed Monitoring Wells
KMnO ₄ Field Monitoring Labor	10	EA	\$700	\$7,000	
Labor - Site Superintendent	200	HR	\$40	\$8,000	Two Injection Events Two weeks each
Labor - Field Engineer	200	HR	\$30	\$6,000	
Labor - Procurement Manager	40	HR	\$30	\$1,200	
SUBTOTAL - Injection and Monitoring				\$67,983	
Hydraulic Containment - Groundwater Extraction					
Land Use Controls	1	EA	\$52,100	\$52,100	
Land Use Controls	1	EA	\$5,000	\$5,000	
SUBTOTAL				\$138,383	
Project Management	5%	of	\$138,383	\$6,919	
Remedial Design	10%	of	\$138,383	\$13,838	
Construction Management	2%	of	\$138,383	\$2,768	
Subcontractor General Requirements	2%	of	\$138,383	\$2,768	
SUBTOTAL				\$164,676	
Contingency	15%	of	\$164,676	\$24,701	
TOTAL CAPITAL COST				\$189,400	

Site: Charleston Naval Complex
Location: AOC 607
Phase: Corrective Measures Study
Base Year: 2004
Date: August 2003

Description: Potassium permanganate injection in the shallow interval of the surficial aquifer.

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Potassium Permanganate Injection					
Potassium Permanganate	0	LB	\$1.35	\$0	Two injection events separated by 6 months Assume 14,000 gallons of 3% KMnO ₄ injected solution during each injection event. 3,142 pounds of KMnO ₄ per event or 6,284 pounds for the two events.
Shipping - Potassium Permanganate Equipment	0	LS	\$600.00	\$0	
PPE	0	Event	\$100	\$0	Two Injection Events
Decon Equipment/Waste Handling Materials	0	Event	\$200	\$0	Two weeks each
Miscellaneous Materials/Supplies	0	Event	\$200	\$0	
Performance Monitoring					
KMnO ₄ Lab Sampling	0	EA	\$5,800	\$0	Sample 5 Existing and 6 Proposed Monitoring Wells
KMnO ₄ Field Monitoring Labor	0	EA	\$700	\$0	
Labor - Site Superintendent	0	HR	\$40	\$0	Two Injection Events
Labor - Field Engineer	0	HR	\$30	\$0	Two weeks each
Labor - Procurement Manager	0	HR	\$30	\$0	
SUBTOTAL - Injection and Monitoring				\$0	
Hydraulic Containment -					
Groundwater Extraction	1	EA	\$12,000	\$12,000	
Land Use Controls	1	EA	\$1,100	\$1,100	
Annual Report					
Labor - Project Manager	0	HR	\$125	\$0	
Labor - Engineer/Hydrogeologist	0	HR	\$90	\$0	
Labor - Editor	0	HR	\$65	\$0	
Labor - CAD Technician	0	HR	\$65	\$0	
SUBTOTAL - Annual Report				\$0	
TOTAL ANNUAL O&M COST				\$13,000	

PRESENT VALUE ANALYSIS

Discount Rate = 3.2%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	TOTAL PRESENT VALUE	NOTES
1	FIRST YEAR CAPITAL COST	\$189,400	\$189,400	\$189,400	
2- 20	ANNUAL O&M COST (Year 1 - 5)	\$18,800	\$18,800	\$274,594	Annual Sampling Yrs 1-20 Assume 5 Yr Injection Plan - 2 Injections Per Year Containment for 5 Years LUCs for 20 Years
				\$463,994	
	TOTAL PRESENT WORTH OF ALTERNATIVE			\$464,000	

SOURCE INFORMATION

Alternative 3: **Monitoring/Natural Attenuation****COST ESTIMATE SUMMARY**

Site: Charleston Naval Complex

Description: Monitoring/natural attenuation of the surficial aquifer.

Location: AOC 607

Phase: Corrective Measures Study

Base Year: 2004

Date: August 2003

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Monitoring Well Installation Monitoring/Natural Attenuation Work Plan Groundwater Contingency Plan	1	EA	\$0	\$0	No Monitoring Well Installation - Use Existing Network
Labor - Project Manager	12	HR	\$125	\$1,500	
Labor - Engineer/Hydrogeologist	40	HR	\$90	\$3,600	
Labor - Editor	16	HR	\$65	\$1,040	
Labor - CAD Technician	16	HR	\$65	\$1,040	
Monitoring/Natural Attenuation Groundwater Sample Collection Event	1	EA	\$10,200	\$10,200	Sample 26 Existing Monitoring Wells
SUBTOTAL				\$17,380	
Hydraulic Containment - Groundwater Extraction	1	EA	\$52,100	\$52,100	
Land Use Controls	1	EA	\$5,000	\$5,000	
Project Management	5%	of	\$17,380	\$869	
Technical Support	5%	of	\$17,380	\$869	
Construction Management	0%	of	\$17,380	\$0	
Subcontractor General Requirements	5%	of	\$17,380	\$869	
SUBTOTAL				\$77,087	
Contingency	15%	of	\$77,087	\$11,563	
TOTAL CAPITAL COST				\$88,700	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Annual Groundwater Sample Collection Event	1	EA	\$10,200	\$10,200	
Hydraulic Containment - Groundwater Extraction	1	EA	\$12,000	\$12,000	
Land Use Controls	1	EA	\$1,100	\$1,100	
Annual Report					
Labor - Project Manager	12	HR	\$125	\$1,500	
Labor - Engineer/Hydrogeologist	24	HR	\$90	\$2,160	
Labor - Editor	12	HR	\$65	\$780	
Labor - CAD Technician	12	HR	\$65	\$780	
SUBTOTAL				\$28,520	
TOTAL ANNUAL O&M COST				\$29,000	

Site: Charleston Naval Complex**Description:** Monitoring/natural attenuation of the surficial aquifer.**Location:** AOC 607**Phase:** Corrective Measures Study**Base Year:** 2004**Date:** August 2003**PRESENT VALUE ANALYSIS**

Discount Rate = 3.2%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	TOTAL PRESENT WORTH	NOTES
1	FIRST YEAR CAPITAL COST	\$88,700	\$88,700	\$88,700	
1 - 5	ANNUAL O&M COST (Year 1 - 5)	\$29,000	\$29,000	\$321,041	Containment for 20 Years Annual Sampling
6 - 20	ANNUAL O&M COST (Year 6 - 20)	\$17,000	\$17,000	\$409,741	
TOTAL PRESENT WORTH OF ALTERNATIVE				\$410,000	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).