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CORRECTIVE MEASURES STUDY REPORT PILOT STUDY WORK PLAN AREA OF  
CONCERN 607 (AOC 607) ZONE F CNC CHARLESTON SC  
1/26/2005  
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***

*October 2003*

*Contract N62467-99-C-0960*

# CH2MHILL TRANSMITTAL

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**Date:** January 26, 2005

**Re:** Revision 1 replacement pages for *Corrective Measures Study Report/Pilot Study Work Plan, AOC 607, Zone F, Revision 0* – Originally Submitted on October 10, 2003

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  - REVISED CERTIFICATION PAGE
  - REVISED TABLE OF CONTENTS
  - REVISED PAGES 1-1 THROUGH 1-3
    - REVISED SECTION 2.0 TEXT
      - REVISED PAGE 3-1
  - REVISED PAGES 4-1, 4-2, 4-7, AND 4-9
    - REVISED SECTION 5.0 TEXT
    - REVISED SECTION 6.0
-

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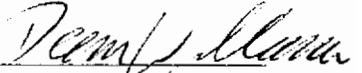
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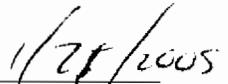
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I, Dean Williamson, certify that this report has been prepared under my direct supervision. The data and information are, to the best of my knowledge, accurate and correct, and the report has been prepared in accordance with current standards of practice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

South Carolina

Permit No. 21428

  
\_\_\_\_\_  
Dean Williamson, P.E.

  
\_\_\_\_\_  
Date

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# 1.0 Introduction

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

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

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

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

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

The CMS report also presents a summary of the Interim Measure (IM) completed at the site, as documented in the *Interim Measure Completion Report/CMS Work Plan/Investigation Work Plan, AOC 607, Zone F, Revision 0* (CH2M-Jones, 2003); a summary of the chemicals of 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 **2.0 Site Conditions Summary**

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

### 6 **2.1 Site Geology**

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

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

### 26 **2.2 Site Hydrology and Hydrogeology**

27 The surface hydrology of Zone F is controlled by a system of storm sewers and drainage  
28 swales, which in turn drain east through Zone E to the Cooper River. The local  
29 hydrogeology consists of an unconfined aquifer system within the Quaternary deposits,

1 with the underlying Ashley Formation acting as a lower bounding unit. The unconfined  
2 aquifer varies in total thickness from approximately 21 to 35 feet thick in Zone F. Depth to  
3 groundwater is typically 4 to 5 ft bls.

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

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

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

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

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

## 28 **2.3 Phase I and II IM Summary**

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

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

14 VOC contamination in the deeper portion of the surficial aquifer has been found to be  
15 limited to the vicinity of well F607GW018D. Concentrations of total VOCs in this well have  
16 generally been in the 1,500 to 2,000 µg/L range. The data indicate that no DNAPL  
17 penetration into the deeper zone of the surficial aquifer has occurred at AOC 607. Because of  
18 the limited areal extent of the portion of the deeper surficial aquifer impacted and relatively  
19 low concentrations, an IM in this zone was not considered necessary.

## 20 **2.4 Phase III IM Summary**

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

### 30 **2.4.1 ERH Operation**

31 Thermal Remediation Services, Inc. (Thermal) was subcontracted to design, construct, and  
32 operate the ERH system within the 16,525 square foot (ft<sup>2</sup>) TTA. The *Phase III Interim*  
33 *Measure Work Plan, Electrical Resistance Heating – Source Area Remediation, AOC 607, Zone F,*

1 *Revision 0* (CH2M-Jones, 2001c) outlined the proposed construction and implementation  
2 approach. The ERH system was constructed in August and September 2001, started on the  
3 afternoon of October 3, 2001, and shut down on the morning of July 8, 2002.

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

11 The operation of the ERH system increased from the original design duration of 124 days to  
12 279 days. The extension was due to the drying of the soils in the immediate area around  
13 each electrode, which made the saturated zone less conductive. As a result, various  
14 improvements were made to the electrode design and spacing from October 2001 to April  
15 2002. From April 15 to May 15, 2002, the entire ERH system was operating using 101  
16 electrodes, 12 8-inch diameter steel piles, 6 Geoprobe electrodes, and 310 ¾-inch diameter  
17 ground rods.

## 18 **2.4.2 Recovered Contaminant Mass**

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

## 24 **2.4.3 Performance Monitoring Strategy**

25 Groundwater samples collected as part of the IM were used to evaluate ERH system  
26 performance and to monitor potential contaminant migration during system operation.  
27 Groundwater samples were collected from 12 shallow monitoring wells within the ERH  
28 TTA and analyzed for VOCs using U.S. Environmental Protection Agency (EPA) method  
29 8260B. The monitoring wells located in the TTA are provided in Figure 2-2.

30 To evaluate any effects of the ERH technology on the lower portions of the surficial aquifer  
31 above the Ashley Formation and within the TTA, groundwater samples were collected from  
32 intermediate and deep monitoring wells F607GW06I and F607GW06D, which are located  
33 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 (ft<sup>3</sup>) 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.

## 3.0 RAOs, Proposed MCSs, and Alternative Evaluation Criteria

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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 **4.0 Description of Candidate Corrective** 2 **Measure Alternatives**

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

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

### 18 **4.1 Candidate Approaches for Preventing Contaminated** 19 **Groundwater Migration**

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

28 To date, significant migration of the plume away from the dry cleaner has not occurred. The  
29 most distal portion of the plume is less than approximately 200 feet from the dry cleaner.  
30 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 The RDA may implement repairs to the sanitary sewer line in this area at some time in the  
9 future. Consequently, alternatives that can be implemented to continue to limit the  
10 migration of the plume after this sewer line is repaired are considered as part of this CMS.

11 Leading candidate alternatives for preventing migration of contaminated groundwater  
12 include:

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

15 In addition to these approaches, groundwater monitoring of perimeter wells is an ancillary  
16 technology that will be used to ensure that the selected containment approach is effective.  
17 The two leading candidate containment technologies are described in more detail below.

#### 18 **4.1.1 Hydraulic Containment**

##### 19 **Technology Description**

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

25 The groundwater recovery system removes contaminated groundwater from the affected  
26 aquifer and creates the necessary hydraulic gradients that prevent contaminated  
27 groundwater from migrating away from the groundwater collection area. Groundwater  
28 recovery can be achieved using vertical wells, collection trenches, or horizontal wells.

29 Because the size of the affected aquifer at AOC 607 is relatively small (less than 200 ft by 200  
30 ft) and groundwater to be recovered is shallow, a groundwater recovery system using  
31 conventional vertical recovery wells would likely be adequate for AOC 607.

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 achieved 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 (CO<sub>2</sub>) 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 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 **5.0 Detailed Analysis of Alternatives**

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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  $\text{KMnO}_4$  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  $\text{KMnO}_4$  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  $\text{KMnO}_4$  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  $\text{KMnO}_4$  would be delivered during each injection event.

12 The design concentration of  $\text{KMnO}_4$  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.

## 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  $\text{KMnO}_4$ . 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.

CH2M HILL

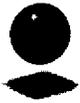
115 Perimeter Center P...

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**CH2MHILL**

October 10, 2003

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

Re: CMS Report/Pilot Study Work Plan (Revision 0) – AOC 607, Zone F

Dear Mr. Scaturo:

Enclosed please find two copies of the CMS Report/Pilot Study Work Plan (Revision 0) for AOC 607 in Zone F of the Charleston Naval Complex (CNC). This report has been prepared pursuant to agreements by the CNC BRAC Cleanup Team for completing the RCRA Corrective Action process.

Please contact me at 352/335-5877, ext. 2280, if you have any questions or comments.

Sincerely,

CH2M HILL

Dean Williamson, P.E.

cc: Dann Spariosu/USEPA, w/att  
Rob Harrell/Navy, w/att  
Gary Foster/CH2M HILL, w/att

# 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***

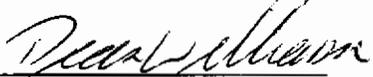
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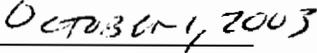
*Revision 0  
Contract N62467-99-C-0960  
158814.ZF.EX.05*

## **Certification Page for Corrective Measures Study Report/Pilot Study Work Plan (Revision 0) – 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

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2	AOC	area of concern
3	BCT	BRAC Cleanup Team
4	BRAC	Base Realignment and Closure
5	C <sub>3</sub> H <sub>5</sub> KO <sub>3</sub>	potassium lactate
6	CO <sub>2</sub>	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 <sup>3</sup>	cubic feet

# 1 **Acronyms and Abbreviations, Continued**

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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 <sub>4</sub>	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**

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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



# 1 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 portion of the surficial aquifer at AOC 607 and develops the  
21 basis for selection of a CA alternative that prevents contaminant migration, ensures that  
22 exposure of the groundwater COCs to human and ecological receptors does not occur, and  
23 can achieve a reduction in COC concentrations in groundwater over time. Shallow  
24 groundwater at AOC 607 is defined as the surficial aquifer interval above the competent  
25 clay layer located at an approximate elevation of 10 to 11 feet below land surface (ft bls).

26 The CMS report also presents a summary of the Interim Measure (IM) completed at the site,  
27 as documented in the *Interim Measure Completion Report/CMS Work Plan/Investigation Work  
28 Plan, AOC 607, Zone F, Revision 0* (CH2M-Jones, 2003); a summary of the chemicals of  
29 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. The PCE was suspected to be in the shallow aquifer in  
6 the form of a dense non-aqueous phase liquid (DNAPL). Sites with groundwater  
7 contaminated by chlorinated solvent DNAPLs are known to be very difficult, and in many  
8 cases, virtually impossible to remediate to drinking water standards. Although the IM is  
9 believed to have been successful in removing much or most of the PCE DNAPL from the  
10 aquifer, some residual DNAPL may remain at the site. This residual DNAPL makes  
11 complete restoration of the shallow aquifer to its original pristine condition a difficult and  
12 potentially unachievable objective, especially within the short and intermediate term time  
13 frames. It is expected to take many decades for the aquifer to reach its original unimpacted  
14 condition. However, it is likely that decreases in dissolved phase COC concentrations can be  
15 achieved at the site over time. The site can be managed such that the plume does not  
16 migrate further and no human or ecological receptors are exposed to unacceptable  
17 concentrations of COCs. The focus of this CMS is on how to best achieve these objectives at  
18 the site.

19 In addition, an additional deep monitoring well is being installed at the site to assess the  
20 extent of contamination of the deeper portion of the shallow aquifer. If needed, additional  
21 corrective measures will be evaluated to address contamination in this portion of the aquifer  
22 under a separate CMS report.

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

## 27 **1.2 Background**

### 28 **1.2.1 Site History**

29 AOC 607 consists of a former dry cleaning facility, Building 1189, that supported the former  
30 local seamen's housing from 1942 to 1986. Building 225, a former Naval Lodge, is located  
31 immediately west of AOC 607. Toward the end of its operational period, the dry cleaning  
32 facility was used as a general purpose laundry with two industrial washers and dryers.

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

## 8 **1.2.2 General Source Area Description**

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

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

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

## 1 **1.3 Report Organization**

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

4 **1.0 Introduction** — Presents the purpose and scope of the CMS Report and PSWP, as well  
5 as relevant background information, including site history and a description of the  
6 source area within the shallow portion of the surficial aquifer.

7 **2.0 Site Condition Summary** — Presents a site-specific summary of existing conditions,  
8 including site geology and hydrogeology, nature and extent of contamination, and a  
9 summary of the risk assessment, and most notably the groundwater COCs identified at  
10 the site.

11 **3.0 RAOs, Proposed MCSs, and Alternative Evaluation Criteria** — Presents the remedial  
12 action objectives (RAOs) of this CMS and the proposed MCSs for VOCs in groundwater.

13 **4.0 Description of Candidate Corrective Measure Alternatives** — Describes each of the  
14 candidate corrective measure alternatives for contaminant concentration reduction in  
15 the shallow interval of the surficial aquifer.

16 **5.0 Detailed Analysis of Alternatives** — Presents the applicable treatment technologies  
17 considered for groundwater remediation and a description of the technology screening  
18 process. The section also summarizes the factors and methodology used to evaluate and  
19 rank the corrective measure alternatives and the results of the evaluation.

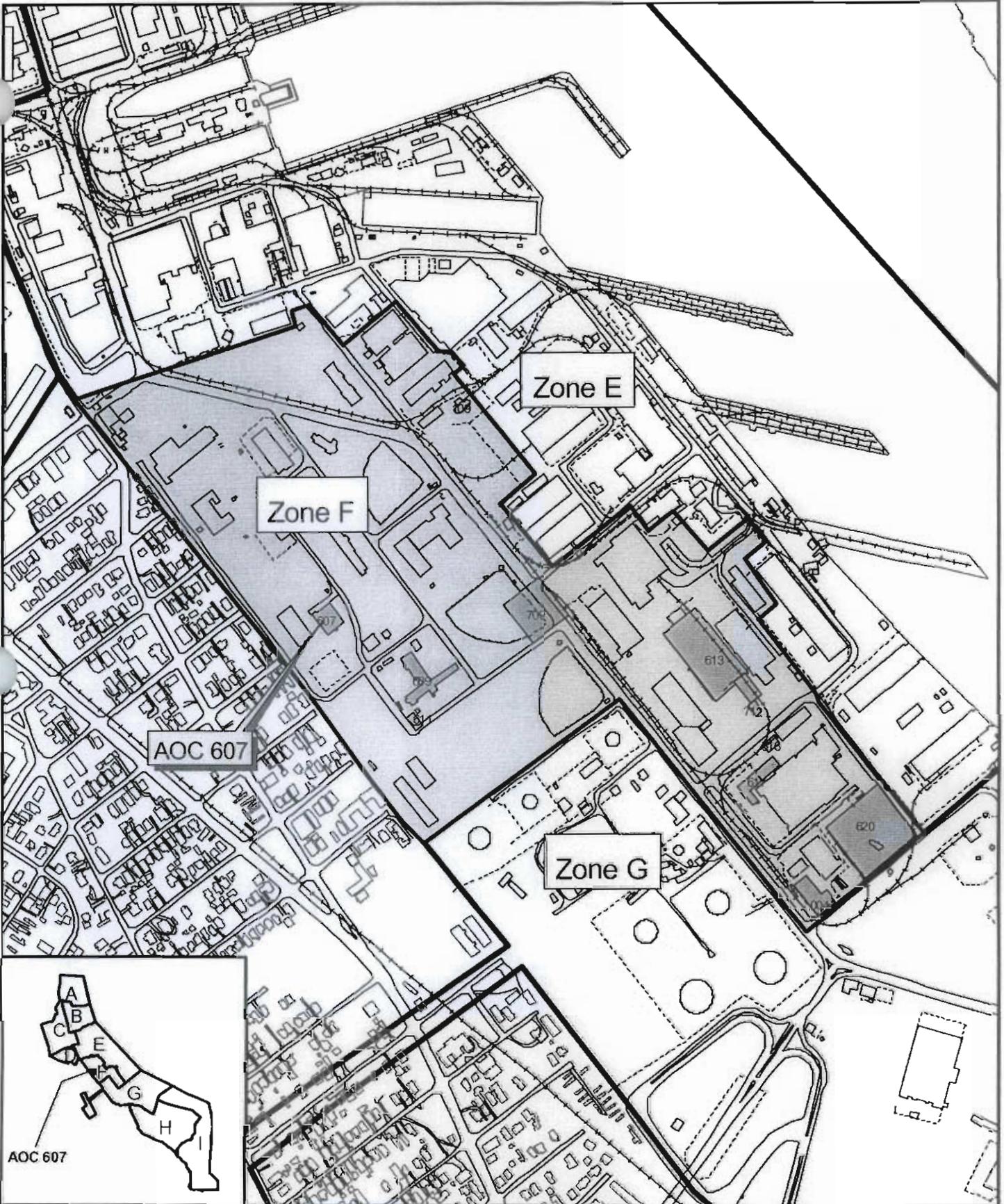
20 **6.0 Recommended Corrective Measure Alternative** — Describes the preferred corrective  
21 measure alternative to achieve the MCSs and remedial goal options (RGOs) for  
22 contaminant concentration reduction at AOC 607, based on a comparison of the  
23 alternatives.

24 **7.0 Pilot Study Work Plan** — Presents the approach for evaluating the site-specific  
25 technology effectiveness in the shallow interval of the surficial aquifer.

26 **8.0 References** — Lists the references used in this document.

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

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



- Zone F Boundary
- SWMU/AOC Within Zone F Boundary



0                      800                      1600 Feet

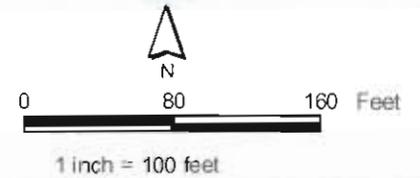
1 inch = 800 feet

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

NOTE: All Data is 1997  
 NOTE: Original figure created in color

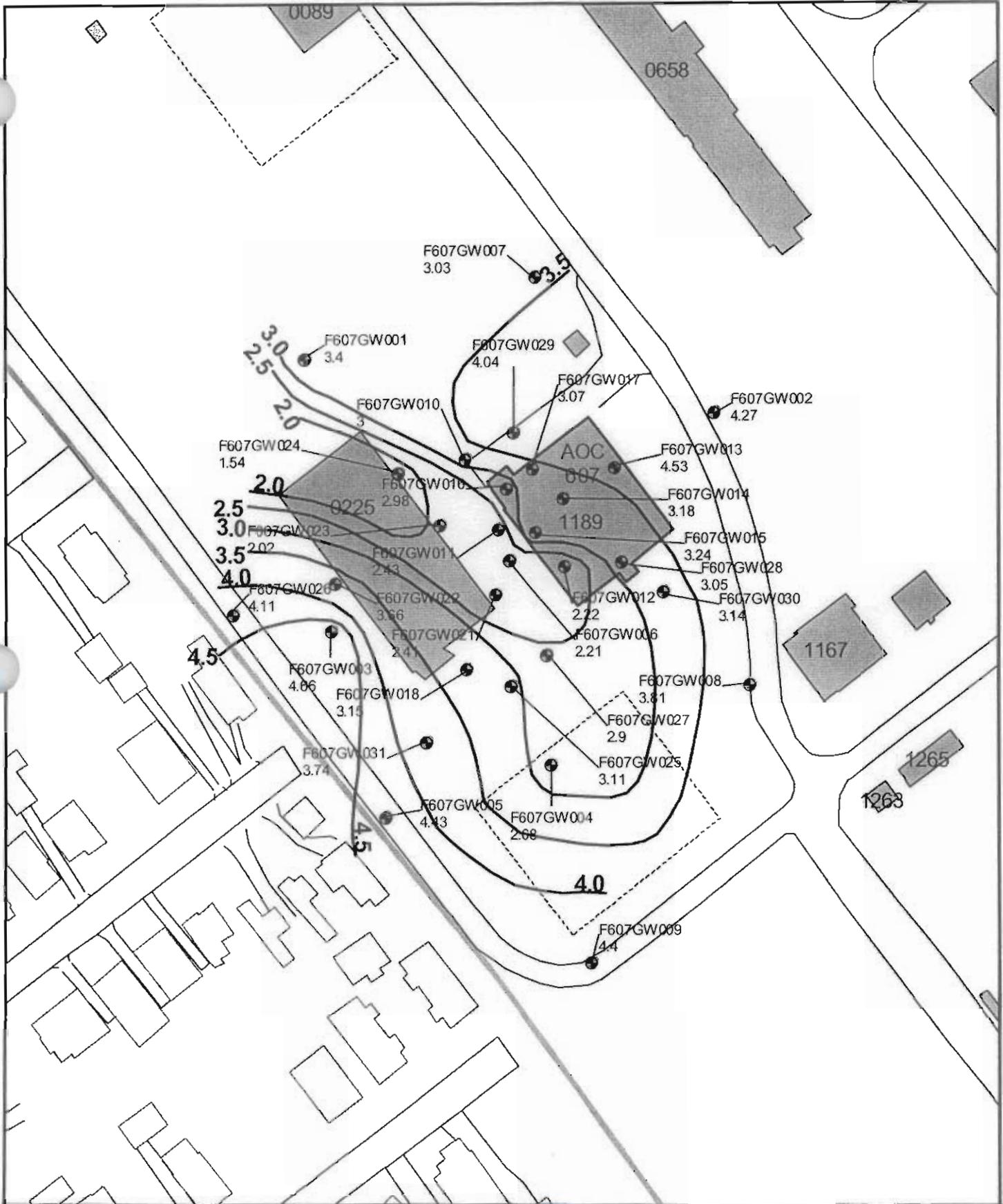


- Monitoring Well
- ▬ Fence
- ▬ Roads
- ▬ STORM-LINE/MANHOLE
- ▬ SEWER-LINE/MANHOLE
- ▭ AOC Boundary
- ▭ Buildings
- ▭ Zone Boundary



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

**CH2MHILL**

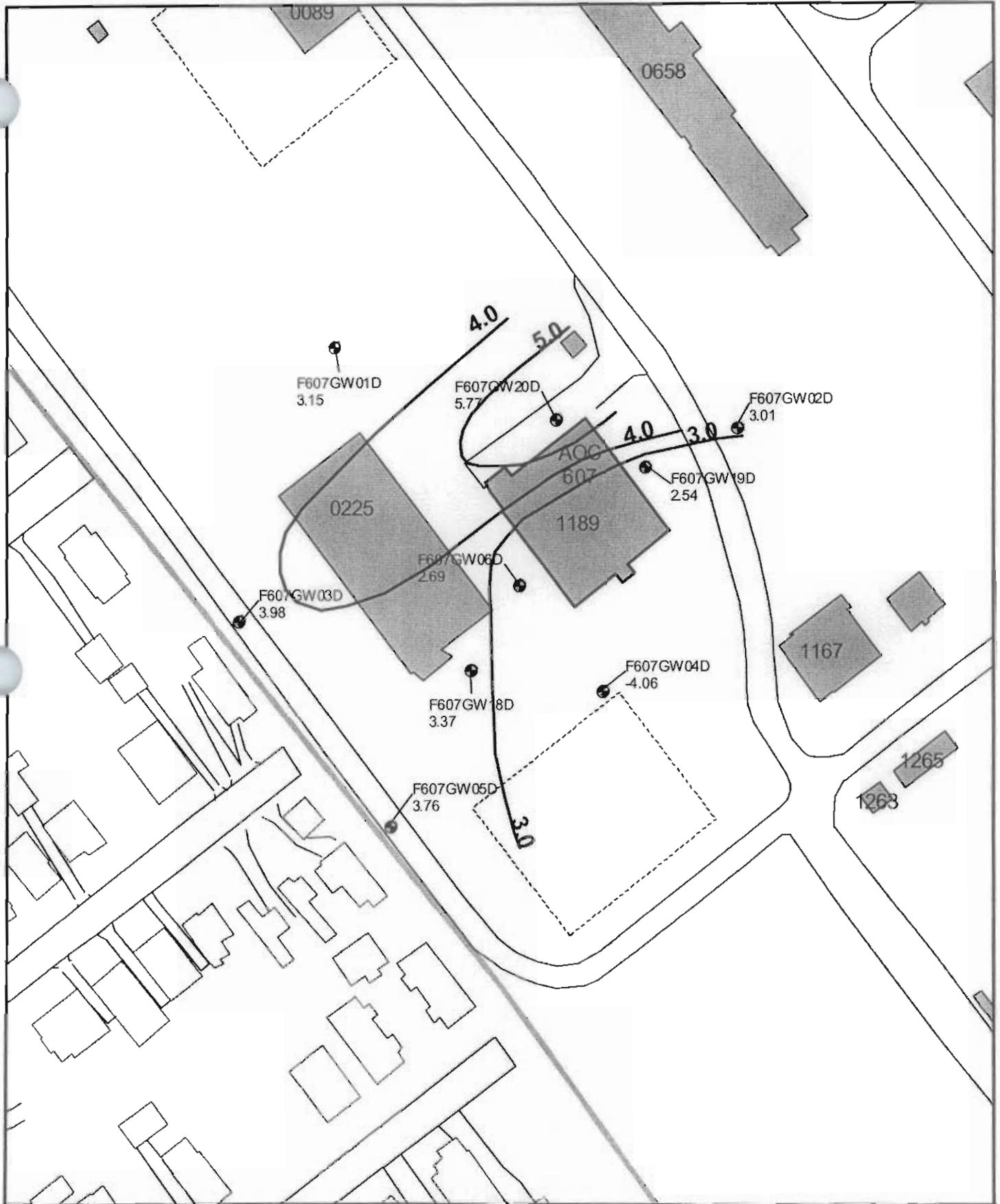


**Figure 1-3**  
 Shallow Groundwater Potentiometric Surface  
 AOC 607, Zone F  
 Charleston Naval Complex

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

100 0 100 Feet  
 1 inch = 100 feet





- Monitoring Well (Groundwater Elevations in ft msl)
- ✓ Groundwater Contours 1.0 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



## 1 **2.0 Site Conditions Summary**

---

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

### 6 **2.1 Site Geology**

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

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

### 26 **2.2 Site Hydrology and Hydrogeology**

27 The surface hydrology of Zone F is controlled by a system of storm sewers and drainage  
28 swales, which in turn drain east through Zone E to the Cooper River. The local  
29 hydrogeology consists of an unconfined aquifer system within the Quaternary deposits,  
30 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  $\mu\text{g}/\text{L}$ , 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 **2.4 Phase III IM Summary**

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

### 23 **2.4.1 ERH Operation**

24 Thermal Remediation Services, Inc. (Thermal) was subcontracted to design, construct, and  
25 operate the ERH system within the 16,525 square foot ( $\text{ft}^2$ ) TTA. The *Phase III Interim*  
26 *Measure Work Plan, Electrical Resistance Heating – Source Area Remediation, AOC 607, Zone F,*  
27 *Revision 0* (CH2M-Jones, 2001c) outlined the proposed construction and implementation  
28 approach. The ERH system was constructed in August and September 2001, started on the  
29 afternoon of October 3, 2001, and shut down on the morning of July 8, 2002.

30 The ERH system used two 500 kilowatt (kW) power control units (PCU 500-1 and PCU 500-  
31 2). The original design included 97 electrodes installed to a depth of approximately 10 to  
32 10.5 ft bls. The site was divided into two portions based on when the PCUs were used. The  
33 more contaminated southern portion began heating on October 3, 2001. The northern

1 portion of the site, which included the asphalt parking area outside Buildings 1189 and 225  
2 and immediately north of monitoring well F607GW011, and the area immediately north of  
3 F607GW014 located inside Building 1189, began operation on December 13, 2001.

4 The operation of the ERH system increased from the original design duration of 124 days to  
5 279 days. The extension was due to the drying of the soils in the immediate area around  
6 each electrode, which made the saturated zone less conductive. As a result, various  
7 improvements were made to the electrode design and spacing from October 2001 to April  
8 2002. From April 15 to May 15, 2002, the entire ERH system was operating using 101  
9 electrodes, 12 8-inch diameter steel piles, 6 Geoprobe electrodes, and 310 ¾-inch diameter  
10 ground rods.

## 11 **2.4.2 Recovered Contaminant Mass**

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

## 17 **2.4.3 Performance Monitoring Strategy**

18 Groundwater samples collected as part of the IM were used to evaluate ERH system  
19 performance and to monitor potential contaminant migration during system operation.  
20 Groundwater samples were collected from 12 shallow monitoring wells within the ERH  
21 TTA and analyzed for VOCs using U.S. Environmental Protection Agency (EPA) method  
22 8260B. The monitoring wells located in the TTA are provided in Figure 2-2.

23 To evaluate any effects of the ERH technology on the lower portions of the surficial aquifer  
24 above the Ashley Formation and within the TTA, groundwater samples were collected from  
25 intermediate and deep monitoring wells F607GW06I and F607GW06D, which are located  
26 adjacent to monitoring well F607GW006. The analytical results obtained from the samples  
27 collected from these wells were not used in calculating percent reduction in the dissolved  
28 phase, since they are not screened in the ERH TTA.

29 The 14 monitoring wells inside the ERH TTA were sampled in September 2001, prior to  
30 ERH system startup; monthly from February 2002 until immediately following system  
31 shutdown in July 2002; and in January 2003, six months following shutdown. In addition,  
32 six of the monitoring wells were sampled in the southern portion of the TTA in January  
33 2002.

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

## 7 **2.4.4 Performance Monitoring Results**

### 8 **Inside the ERH Target Treatment Area**

9 Analytical results from the 12 shallow wells sampled during the January 2003 sampling  
10 event were compared to the results from the initial sampling event completed in September  
11 2001. The overall dissolved-phase VOC reduction, using the total summation of detected  
12 concentrations of chlorinated solvents from the 12 shallow wells, was only 21 percent  
13 (largely due to detection of 1,2,-DCE in one well after completion of the ERH  
14 activities). Overall PCE reduction was 64.8 percent. Analytical results from the samples  
15 collected from the 12 shallow and 2 intermediate or deep wells within the TTA during the 9  
16 sampling events are summarized in Table 2-1.

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

24 Four of the 12 shallow monitoring wells (F607GW015, F607GW016, F607GW017, and  
25 F607GW029) had a decrease in total CVOC dissolved concentration greater than 90 percent  
26 compared to the results from the September 2001 sampling event. Monitoring well  
27 F607GW021 had a total CVOC reduction of 88.7 percent, and six of the remaining seven  
28 wells showed a total CVOC reduction ranging from 5.5 percent (F607GW028) to 54.3 percent  
29 (F607GW025). Nominal percent reduction in monitoring well F607GW028 is due to  
30 reductive dechlorination and the elevated cis-1,2-DCE concentration of 29,000 µg/L.

31 Using the groundwater data from the September 2001 sampling event, the Environmental  
32 Visualization System (EVS) software calculated a total CVOC dissolved plume volume of  
33 0.017 cubic feet (ft<sup>3</sup>) and a mass of 1.698 pounds at a total concentration of 1,000 µg/L or

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

### 11 **Outside the ERH Target Treatment Area**

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

27 Overall CVOC contaminant concentrations decreased in the seven shallow monitoring wells  
28 outside the ERH TTA when compared to the results from the September 2001 and October  
29 2003 sampling events. This substantiates that the surficial aquifer outside the ERH TTA was  
30 not impacted from system operation and that contaminant migration did not occur during  
31 ERH system operation.

## 2.4.5 Evaluation of the IM Results

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

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

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

## 2.5 Shallow Interval Groundwater COCs

Groundwater COCs in the shallow interval of the surficial aquifer as identified in the *Interim Measure Completion Report/CMS Work Plan/Investigation Work Plan, AOC 607, Zone F, Revision 0* (CH2M-Jones, 2003) include five CVOCs: 1,1-DCE, PCE, TCE, cis-1,2-DCE, and vinyl chloride. The extent of these groundwater COCs are defined through 28 site monitoring wells installed with the bottom portion of the well screen positioned at the top of the clay layer. Analytical data from samples collected during the January 2003 sampling event were used to depict the distribution of total CVOCs and PCE at 6 months following ERH system shutdown, as shown in Figures 2-5 and 2-6, respectively.

## 2.6 Summary of Risk Assessment

A human health risk assessment for AOC 607 was performed and documented in the *Zone F RFI Report, Revision 0* (Section 10.4.8) for chemicals of potential concern (COPCs) that had been identified in the preliminary screening process. According to the RFI risk assessment,

1 impacted environmental media at AOC 607 included surface soil and groundwater. The RFI  
2 risk assessment evaluated exposure to surface soil on site under both the unrestricted  
3 (residential) and site worker (industrial) land use scenarios: dermal contact with  
4 contaminated surface soil, incidental ingestion of surface soil, inhalation of volatiles  
5 emanating from surface and subsurface soils, ingestion of groundwater through potable use,  
6 and inhalation of VOCs resulting from domestic or process use of groundwater.

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

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

20 As a result of the COC refinement, the chemicals retained as COCs for shallow,  
21 intermediate, and deep groundwater at AOC 607 are PCE, TCE, cis-1,2-DCE, and vinyl  
22 chloride. 1,1-DCE was also retained as a shallow and intermediate groundwater COC. The  
23 COCs identified in the shallow portion of the surficial aquifer were used to evaluate  
24 remedial alternatives in this CMS report.

25

Table 2-1  
 Analytes Detected in Groundwater Monitoring Wells Within the ERH Target Treatment Area  
 CMS Report/Pit/ 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)	BDCM (ug/L)	Chloroform (ug/L)	Carbon Disulfide (ug/L)	DBCM (ug/L)	Bromoform (ug/L)	Methylene Chloride (ug/L)	Benzene (ug/L)	Toluene (ug/L)	Acetone (ug/L)	MEK (ug/L)	Bromomethane (ug/L)	Chlorobenzene (ug/L)	1,2-DCB (ug/L)	1,4-DC3 (ug/L)	2-Hexanone (ug/L)	1,2,3-TCB (ug/L)	1,2,4-TCB (ug/L)
Shallow Monitoring Wells Located Within the ERH Target Treatment Area																									
F607GW006	09/20/2001	250U	250U	370	370	380	6,800	500U	250U	250U	250U	250U	250U	250U	16J	250U	500U	500U	500U	250U	250U	250U	500U	250U	250U
	01/07/2002	5.0U	0.85J	28	29	15	150	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	0.29J	5.0U	2,200	130	10U	5.0U	5.0U	100	10U	5.0U	5.0U
	02/06/2002	10U	10U	17	17	8.1J	110	20U	10U	10U	10U	10U	10U	10U	10U	10U	1,200	100	20U	10U	10U	10U	20U	10U	10U
	03/13/2002	20U	20U	14J	14J	11J	166	40U	20U	20U	20U	20U	20U	20U	20U	20U	1,500	150	40U	20U	20U	20U	40U	20U	20U
	04/09/2002	25U	25U	15J	15J	12J	126	50U	25U	25U	25U	25U	25U	25U	25U	25U	1,100	76	50U	25U	25U	25U	50U	25U	25U
	05/02/2002	5.0U	5.0U	11	11	9.7	120	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	0.37J	5.0U	1,000	100	10U	5.0U	5.0U	10U	5.0U	5.0U
	06/05/2002	5.0U	5.0U	6.9	6.9	7.1	160	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	1,800	120	10U	5.0U	5.0U	5.0U	10U	5.0U	5.0U
	07/12/2002	10U	10U	26	26	36	366	20U	10U	10U	10U	10U	10U	10U	10U	10U	2,000	150	20U	10U	10U	10U	20U	10U	10U
	01/09/2003	250U	250U	450	450	400	5,400	20U	250U	250U	250U	250U	250U	250U	250U	250U	250U	500U	500U	500U	250U	250U	500U	250U	250U
F607GW011	09/20/2001	250U	250U	440	440	430	5,600	500U	250U	250U	250U	250U	250U	250U	250U	250U	500U	500U	500U	250U	250U	250U	500U	250U	250U
	01/07/2002	120U	120U	490	490	520	5,000	27J	120U	120U	120U	120U	120U	120U	120U	120U	2,400	250U	100U	120U	120U	120U	250U	120U	120U
	02/06/2002	100U	100U	190	190	180	2,800	200U	100U	100U	100U	100U	100U	100U	100U	100U	1,700	200U	200U	100U	100U	100U	200U	100U	100U
	03/13/2002	50U	50U	94	94	81	1,400	100U	50U	50U	50U	50U	50U	50U	50U	50U	3,100	220	100U	50U	50U	50U	50U	50U	50U
	04/09/2002	25U	25U	34	34	22J	570	50U	25U	25U	25U	25U	25U	25U	25U	25U	1,800	150	50U	25U	25U	25U	50U	25U	25U
	05/03/2002	50U	50U	140	140	95	1,700	5.6J	50U	50U	50U	50U	50U	50U	50U	2.7J	50U	3,400	320	100U	50U	50U	50U	50U	50U
	06/04/2002	50U	5.9J	110	120	150	2,200	100U	50U	50U	50U	50U	50U	50U	50U	50U	2,700	210	100U	50U	50U	50U	100U	50U	50U
	07/12/2002	25U	25U	86	86	74	1,400	50U	25U	25U	25U	25U	25U	25U	25U	25U	6,600	810	50U	25U	25U	25U	50U	25U	25U
	01/09/2003	250U	30J	210J	240J	330	3,800	250U	250U	250U	250U	250U	250U	250U	250U	250U	250U	500U	500U	500U	250U	250U	500U	250U	250U
F607GW014	09/20/2001	120U	120U	168	180	150	2,900	500U	120U	120U	120U	120U	120U	120U	120U	120U	250U	250U	250U	120U	120U	250U	500U	120U	120U
	02/06/2002	50U	50U	148	140	97	1,300	100U	50U	50U	50U	50U	50U	50U	50U	50U	880	100U	100U	50U	50U	100U	50U	100U	50U
	03/13/2002	50U	5.8J	310	320	230	2,600	100U	50U	50U	50U	50U	50U	50U	50U	50U	1,400	100	100U	50U	50U	50U	100U	50U	50U
	04/08/2002	25U	25U	58	58	36	346	50U	25U	25U	25U	25U	25U	25U	25U	25U	1,500	180	50U	25U	25U	25U	50U	25U	25U
	05/03/2002	10U	2.2J	65	67	39	498	20U	10U	10U	10U	10U	10U	10U	10U	10U	2,400	170	20U	10U	2.8J	10U	20U	10U	10U
	06/04/2002	20U	2.5J	60	63	42	388	40U	20U	20U	20U	20U	20U	20U	20U	20U	1,900	150	40U	20U	20U	20U	40U	20U	
	07/10/2002	25U	7.2J	140	150	74	718	50U	25U	25U	25U	25U	25U	25U	1.7J	25U	4,600	440	50U	25U	25U	25U	50U	25U	25U
	01/09/2003	100U	100U	120	130	210	1,700	200U	100U	100U	100U	100U	100U	100U	100U	100U	200U	200U	200U	100U	100U	100U	200U	100U	100U
	F607GW015	09/20/2001	100U	100U	190	190	250	2,100	200U	100U	100U	100U	100U	100U	100U	100U	100U	200U	200U	200U	100U	100U	100U	200U	100U
02/06/2002		50U	50U	140	140	120	1,700	100U	50U	50U	50U	50U	50U	50U	50U	50U	2,300	240	100U	50U	50U	100U	50U	50U	
03/13/2002		50U	50U	72	72	51	930	100U	50U	50U	50U	50U	50U	50U	50U	50U	2,000	180	100U	50U	50U	100U	50U	50U	
04/08/2002		100U	100U	52J	52J	490	200U	100U	100U	100U	100U	100U	100U	100U	100U	100U	3,900	320	200U	100U	100U	200U	100U	100U	
05/03/2002		120U	120U	86J	86J	66J	910	250U	120U	120U	120U	120U	120U	120U	120U	120U	5,500	540	250U	120U	120U	250U	120U	120U	
06/04/2002		100U	14J	280	300	270	7,600	200U	100U	100U	100U	100U	100U	100U	100U	5.4J	100U	5,100	870	200U	100U	100U	200U	100U	
07/10/2002		5.0U	1.3J	48	50	18	290	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.5	0.88J	2,300	310	10U	5.0U	5.0U	5.0U	10U	5.0U	
01/09/2003		5.0U	5.0U	7.4	7.4	7.2	28	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10U	10U	10U	5.0U	5.0U	5.0U	10U	5.0U	
F607GW016		09/20/2001	12U	3.3J	310	310	59	260	1.7J	12U	12U	12U	12U	12U	12U	12U	12U	25U	25U	25U	12U	12U	25U	12U	12U
	02/06/2002	20U	20U	420	420	81	200	8.7J	20U	20U	15J	20U	20U	20U	20U	12J	720	84	40U	20U	20U	20U	20U	20U	
	03/13/2002	120U	120U	180	180	40J	42J	250U	120U	120U	120U	120U	120U	120U	6.6J	120U	4,400	540	250U	120U	120U	250U	120U	120U	
	04/09/2002	5.0U	2.2J	110	110	24	38	3.2J	5.0U	5.0U	1.6J	5.0U	5.0U	5.0U	5.5	1.6J	3,200	400	10U	5.0U	5.0U	10U	5.0U		
	05/03/2002	5.0U	1.8J	92	94	18	18	2.2J	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	8.0	1.3J	4,400	480	10U	5.0U	5.0U	10U	5.0U		
	06/04/2002	5.0U	2.9J	78	81	28	28	2.3J	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.2	0.74J	3,000	320	10U	5.0U	5.0U	10U	5.0U		
	07/10/2002	5.0U	2.3J	82	85	24	34	2.2J	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	12.0	5.0U	4,400	920	10U	5.0U	5.0U	10U	5.0U		
	01/10/2003	0.84J	1.4J	37	38	1.2J	5.0U	0.65J	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	0.0U	0.36J	1.8J	10U	10U	10U	5.0U	5.0U	10U	5.0U	
	F607GW017	09/20/2001	5.0U	10J	30	30	12	83	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	6.4	310	10U	5.0U	5.0U	10U	5.0U	10U	5.0U
02/06/2002		10U	10U	6.8J	6.8J	2.6J	4.5J	20U	10U	10U	10U	10U	10U	0.82J	10U	2.8J	410	28	20U	10U	10U	10U	10U		
03/13/2002		50U	50U	26J	26J	10J	23J	100U	50U	50U	50U	50U	50U	50U	50U	2,300	220	100U	50U	50U	100U	50U	50U		
04/09/2002		5.0U	5.0U	4.8J	4.8J	1.8J	5.8	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	0.28J	7.6	2,400	260	16	5.0U	5.0U	10U	5.0U		
05/03/2002		10U	10U	14	14	4.8J	12	20U	10U	10U	10U	10U	10U	10U	10U	3,200	180	20U	10U	10U	10U	10U	10U		
06/04/2002		10U	0.98J	25	26	12	130	20U	10U	10U	10U	10U	10U	10U	1.1J	10U	970	78	20U	10U	10U	20U	10U		
07/10/2002		5.0U	5.0U	7.5	7.5	2.8J	12	10U	5																

**Table 2-1**  
**Analytes Detected in Groundwater Monitoring Wells Within the ERH Target Treatment Area**  
**CMS Report/Pikil 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)	BDCM (ug/L)	Chloroform (ug/L)	Carbon Disulfide (ug/L)	DBCM (ug/L)	Bromoform (ug/L)	Methylene Chloride (ug/L)	Benzene (ug/L)	Toluene (ug/L)	Acetone (ug/L)	MEK (ug/L)	Bromomethane (ug/L)	Chlorobenzene (ug/L)	1,2-DCB (ug/L)	1,4-DCB (ug/L)	2-Hexanone (ug/L)	1,2,3-TCB (ug/L)	1,2,4-TCB (ug/L)
F607GW023	09/26/2001	0.46J	5.0U	30	30	79	830	2.1J	13	12	5.0U	15	3.6J	5.0U	5.0U	5.0U	10U	10U	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
	02/05/2002	20U	20U	54	54	38	350	40U	20U	20U	20U	20U	20U	20U	20U	20U	1,900	240	40U	20U	20U	40U	20U	20U	
	03/13/2002	50U	50U	43J	43J	48J	450	100U	50U	50U	50U	50U	50U	50U	50U	50U	1,900	220	100U	50U	50U	100U	50U	50U	
	04/09/2002	5.0U	5.0U	19	19	18	190	0.52J	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	0.51J	5.0U	1,400	190	10U	5.0U	5.0U	10U	5.0U	5.0U	
	05/02/2002	19U	1.3J	37	38	45	440	1.3J	10U	10U	10U	10U	10U	10U	1.4J	10U	1,500	190	20U	10U	5.9J	10U	20U	10U	
	06/04/2002	5.0U	5.0U	11	11	18	160	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	0.42J	5.0U	220	26	10U	5.0U	5.0U	10U	5.0U	5.0U	
	07/09/2002	0.76J	5.0U	9.1	9.1	20	200	0.64J	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	0.32J	5.0U	2.7J	21	10U	5.0U	5.0U	5.0U	10U	5.0U	
	01/09/2003	1.1J	0.73J	24	25	44	640	1.6J	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	0.94J	10U	10U	10U	5.0U	5.0U	5.0U	5.0U	10U	5.0U	
F607GW025	09/21/2001	250U	250U	250U	250U	230J	4,900	500U	250U	250U	250U	250U	250U	250U	250U	250U	500U	500U	500U	250U	250U	250U	500U	250U	250U
	01/07/2002	250U	250U	370	370	350	7,800	500U	250U	250U	250U	250U	250U	250U	250U	250U	320	500U	500U	250U	250U	250U	500U	250U	250U
	02/05/2002	250U	250U	350	350	300	7,700	500U	250U	250U	250U	250U	250U	250U	250U	250U	500U	500U	500U	250U	250U	250U	500U	250U	250U
	03/13/2002	120U	120U	270	270	180	3,700	250U	120U	120U	120U	120U	120U	120U	120U	120U	350	250U	250U	100U	100U	100U	250U	120U	120U
	04/08/2002	100U	100U	440	440	180	3,100	200U	100U	100U	100U	100U	100U	100U	100U	100U	290	200U	200U	100U	100U	100U	200U	100U	100U
	05/02/2002	100U	100U	210	210	100	1,900	200U	100U	100U	100U	100U	100U	100U	100U	100U	350	200U	200U	100U	100U	100U	200U	100U	100U
	06/05/2002	50U	50U	250	250	140	1,600	100U	50U	50U	50U	50U	50U	50U	50U	50U	300	100U	100U	50U	50U	50U	100U	50U	50U
	07/09/2002	120U	120U	240	240	110J	3,200	250U	120U	120U	120U	120U	120U	120U	120U	54J	370	250U	250U	100U	100U	120U	120U	120U	120U
01/09/2003	1.5J	1.5J	280	280	560	1,500	0.75J	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10U	10U	10U	5.0U	5.0U	5.0U	10U	5.0U	5.0U	
F607GW027	09/21/2001	50U	50U	190	190	930	100U	50U	50U	50U	50U	50U	50U	50U	50U	50U	100U	100U	100U	50U	50U	50U	100U	50U	50U
	01/07/2002	5.0U	5.0U	6	6	9.4	130	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	590	42	10U	5.0U	5.0U	10U	5.0U	5.0U	
	02/05/2002	25U	25U	26	26	23J	490	50U	25U	25U	25U	25U	25U	25U	1.7J	25U	720	88	50U	25U	17J	25U	50U	25U	
	03/13/2002	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10U	10U	10U	5.0U	5.0U	5.0U	10U	5.0U	
	04/08/2002	100U	100U	56J	56J	63J	2,100	200U	100U	100U	100U	100U	100U	100U	100U	100U	260	200U	100U	100U	100U	100U	200U	100U	
	05/02/2002	25U	25U	28	28	88	1,200	50U	25U	25U	25U	25U	25U	25U	1.4J	25U	340	61	50U	25U	8.7J	25U	50U	25U	
	06/05/2002	5.0U	5.0U	1.6J	1.6J	3.4JB	81	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	120	10U	5.0U	5.0U	5.0U	10U	5.0U	5.0U	
	07/09/2002	10U	10U	8.2J	8.2J	11	320	20U	10U	10U	10U	10U	10U	10U	10U	10U	210	21	20U	10U	10U	10U	20U	10U	
01/09/2003	250U	250U	180J	180J	280	3,800	500U	250U	250U	250U	250U	250U	250U	250U	250U	250U	500U	500U	500U	250U	250U	500U	250U	250U	
F607GW028	09/20/2001	1,000U	1,000U	5,200	5,200	6,500	26,000	2,000U	1,000U	1,000U	1,000U	1,000U	1,000U	1,000U	1,000U	1,000U	2,300U	2,000U	2,000U	1,000U	1,000U	1,000U	2,000U	1,000U	1,000U
	01/07/2002	500U	500U	4,600	4,600	5,800	13,000	1,000U	500U	500U	500U	500U	500U	500U	500U	500U	1,300U	1,000U	1,000U	500U	500U	500U	1,000U	500U	
	02/05/2002	500U	500U	3,200	3,200	3,300	13,000	1,000U	500U	500U	500U	500U	500U	500U	500U	500U	1,300U	1,000U	1,000U	500U	500U	500U	1,000U	500U	
	03/13/2002	500U	500U	1,900	1,900	2,100	10,000	1,000U	500U	500U	500U	500U	500U	500U	500U	500U	1,400	1,000U	1,000U	500U	500U	500U	1,000U	500U	
	04/08/2002	120U	120U	1,200	1,200	1,000	4,800	250U	120U	120U	120U	120U	120U	120U	120U	120U	350	250U	200U	100U	100U	100U	250U	120U	
	05/03/2002	100U	100U	340	340	400	2,300	200U	100U	100U	100U	100U	100U	100U	100U	100U	770	200U	200U	100U	100U	100U	200U	100U	
	06/05/2002	100U	100U	230	230	380	1,800	200U	100U	100U	100U	100U	100U	100U	100U	100U	1,400	200U	200U	100U	100U	100U	200U	100U	
	07/10/2002	120U	120U	560	560	580	3,600	250U	120U	120U	120U	120U	120U	120U	12J	120U	83J	1,400	250U	250U	120U	120U	250U	120U	
01/09/2003	71J	150	29,000	29,000	4,400	1,900	87J	100U	100U	100U	100U	100U	100U	100U	100U	200U	200U	200U	100U	100U	100U	200U	100U		
F607GW029	09/21/2001	100U	100U	870	870	870	3,100	200U	100U	100U	100U	100U	100U	100U	100U	100U	200U	200U	200U	100U	100U	100U	200U	100U	
	02/06/2002	50U	4.8J	330	330	290	1,700	17J	50U	50U	50U	50U	50U	50U	50U	50U	780	100U	50U	50U	50U	100U	50U		
	03/13/2002	50U	50U	230	230	170	760	9J	50U	50U	50U	50U	50U	50U	50U	50U	2,100	180	100U	50U	50U	100U	50U		
	04/09/2002	25U	4.1J	190	190	130	600	7.6J	25U	25U	25U	25U	25U	25U	25U	25U	1,100	120	50U	25U	25U	50U	25U		
	05/03/2002	25U	4.3J	120	130	94	460	8.8J	25U	25U	25U	25U	25U	25U	25U	25U	1,500	160	50U	25U	25U	50U	25U		
	06/04/2002	20U	3.9J	100	100	93	340	5.4J	20U	20U	20U	20U	20U	20U	20U	20U	1,500	160	40U	20U	20U	40U	20U		
	07/09/2002	25U	25U	230	230	200	940	11J	25U	25U	25U	25U	25U	25U	2.3J	25U	2,100	260	50U	25U	25U	50U	25U		
	01/09/2003	0.82J	1.1J	37	38	34	140	1.1J	10U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10U	10U	10U	5.0U	5.0U	5.0U	10U	5.0U	
<b>Intermediate and Deep Monitoring Wells Located Within the ERH Target Treatment Area</b>																									
F607GW061	09/20/2001	100U	100U	35J	35J	150	2,400	200U	100U	100U	100U	100U	100U	100U	100U	100U	200U	200U	200U	100U	100U	100U	200U	100U	
	02/05/2002	50U	50U	330	330	150	1,600	100U	50U	50U	50U	50U	50U	50U	50U	50U	100U	100U	100U	50U	50U	50U	100U	50U	
	03/13/2002	4.4J	50U	180	180	240	1,900	5.8J	50U	50U	50U	50U	50U	50U	50U	50U	100U	100U	100U	50U	50U	50U	100U	50U	
	04/09/2002	4.6J	1.3J	110	110	190	1,300	6.3J	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10U	10U	10U	5.0U	5.0U	5.0U	10U	5.0U	
	05/02/2002	12J	50U	95	95	300	2,200	15J</																	

**Table 2-1**

Analytes Detected in Groundwater Monitoring Wells Within 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)	BDCM (ug/L)	Chloroform (ug/L)	Carbon Disulfide (ug/L)	DBCM (ug/L)	Bromoform (ug/L)	Methylene Chloride (ug/L)	Benzene (ug/L)	Toluene (ug/L)	Acetone (ug/L)	MEK (ug/L)	Bromomethane (ug/L)	Chlorobenzene (ug/L)	1,2-DCB (ug/L)	1,4-DCB (ug/L)	2-Hexanone (ug/L)	1,2,3-TCB (ug/L)	1,2,4-TCB (ug/L)
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**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  
 BDCM - Bromodichloromethane  
 DBCM - Dibromochloromethane  
 MEK - Methyl Ethyl Ketone (2-Butanone)  
 1,2-DCB - 1,2-Dichlorobenzene  
 1,4-DCB - 1,4-Dichlorobenzene  
 1,2,3-TCB - 1,2,3-Trichlorobenzene  
 1,2,4-TCB - 1,2,4-Trichlorobenzene

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 PQL 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

ble 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)		
<b>Shallow Monitoring Wells Located Outside the ERH Target Treatment Area</b>																					
F607GW002	09/26/2001	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	5.0U	
	11/08/2001	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	5.0U	
	12/03/2001	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	0.44JB	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	01/08/2002	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	5.0U	
	02/11/2002	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	14	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	03/06/2002	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	0.32J	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
	04/04/2002	4.6J	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	2.3J	5.0U	5.0U	10.0U	5.0U	5.0U	3.0J	4.5J	0.86J	5.0U	5.0U
	05/06/2002	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	14	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	1.5J
	06/06/2002	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	3.6J	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
	07/09/2002	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
	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	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U
F607GW003	09/26/2001	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	5.0U	
	11/08/2001	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	5.0U	
	12/03/2001	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	0.57JB	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	01/08/2002	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	13	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	02/11/2002	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	5.0U	
	03/06/2002	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	5.0U	
	04/05/2002	1.7J	5.0U	1.6J	1.7J	5.0U	5.0U	10.0U	5.0U	5.0U	3.4J	5.0U	14	5.0U	5.0U	5.0U	12	5.4	5.0U	5.0U	
	05/06/2002	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	5.0U	
	06/06/2002	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	07/09/2002	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	0.42J	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	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	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
F607GW004	09/26/2001	5.0U	1.2J	1.30	1.40	1.5	5.0U	1.5J	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	12/03/2001	5.0U	1.0J	1.10	1.10	1.4	5.0U	2.3J	5.0U	0.52JB	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	01/08/2002	5.0U	1.0J	1.10	1.20	1.3	5.0U	2.6J	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	02/11/2002	5.0U	0.79J	78	79	6.8	5.0U	0.95J	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	03/06/2002	5.0U	0.64J	54	54	4.5J	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	10.0U	2.1J	1.4J	5.0U	5.0U	5.0U	5.0U	5.0U	
	04/22/2002	5.0U	0.58J	51	57	4.2J	1.7J	10.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	05/06/2002	5.0U	0.89J	54	55	4.0J	5.0U	0.52J	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	06/06/2002	5.0U	5.0U	62	62	1.5	2.7J	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	07/09/2002	5.0U	5.0U	55	55	1.1	5.0U	0.73J	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	01/14/2003	5.0U	5.0U	1.8J	1.8J	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
	F607GW007	09/26/2001	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	5.0U
11/08/2001		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	5.0U	
12/03/2001		5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	0.46JB	5.0U	5.0U	13	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
01/08/2002		5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	19	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
02/11/2002		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	5.0U	
03/06/2002		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	5.0U	
04/22/2002		5.0U	5.0U	5.0U	5.0U	0.34J	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	5.0U	
05/06/2002		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	5.0U	
06/06/2002		5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
07/09/2002		5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	10.0U	5.0U	5.0U	5.0U	5.0U	5.0U	5.0U	
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	5.0U	10.0U	5.0U	0.59J	5.0U	5.0U	5.0U	5.0U	



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)	
F607GW03D	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	5.0U
F607GW04I	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	5.0U
F607GW04D	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	5.0U
F607GW05D	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	5.0U
F607GW18D	01/14/2003	7.0J	50U	250	250	240	1,300	9.5J	50U	50U	50U	50U	100U	50U	50U	50U	50U	50U	50U	50U
F607GW19D	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	5.0U
F607GW20D	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	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

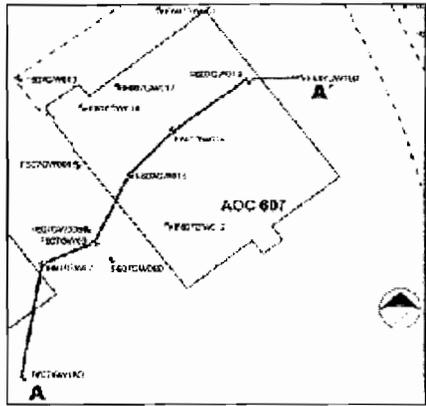
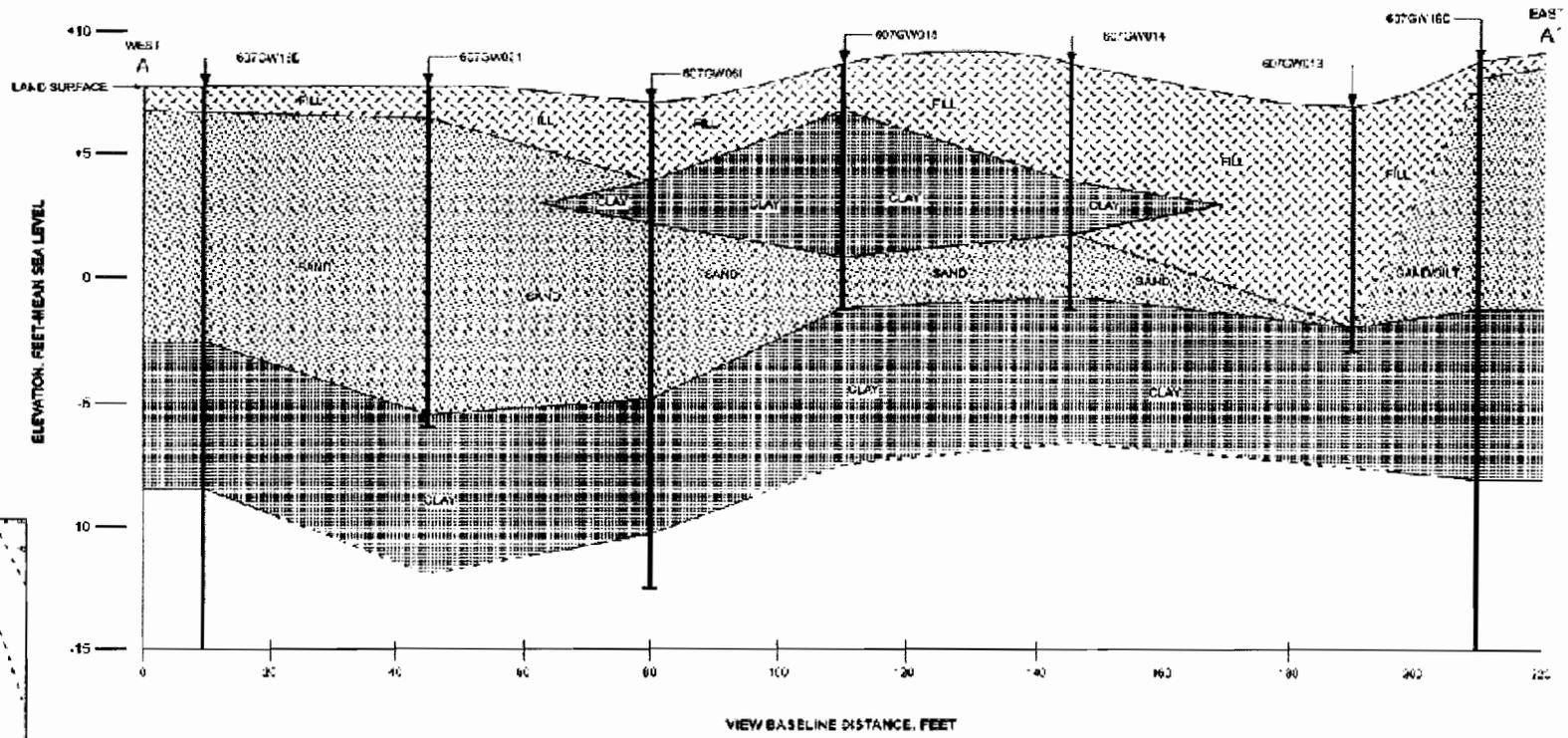
number represented in bold text is an estimated concentration or a detected concentration above the method detection limit.

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 PQL or that the "J" has been applied as a result of the data validation process, and to consider the numeric value as estimated.

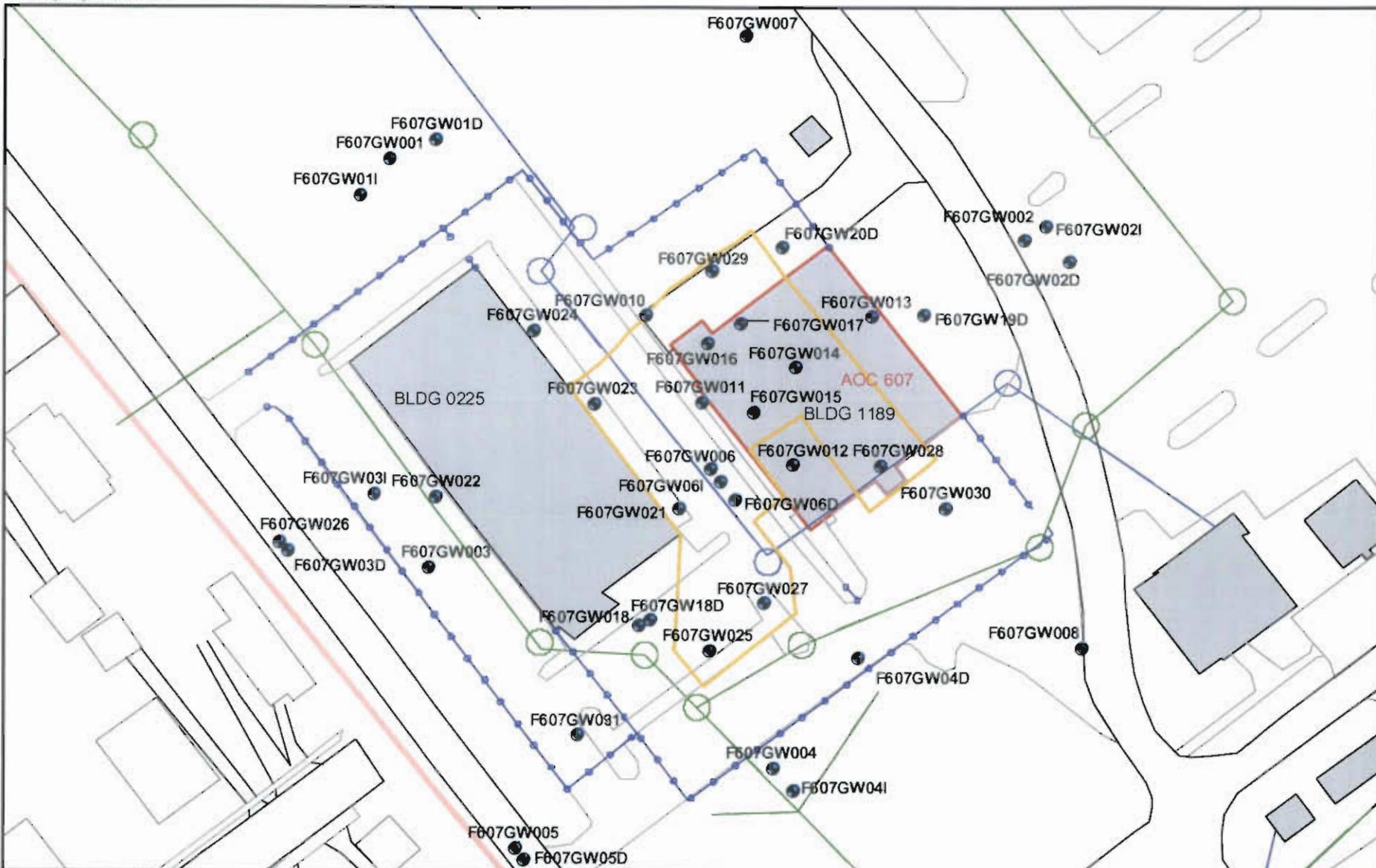
B - target parameter was also detected in the laboratory method blank



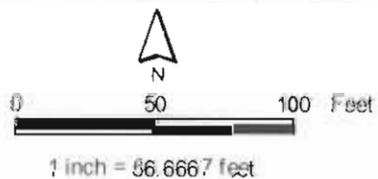
VERTICAL SCALE = 1" = 5'  
 HORIZONTAL SCALE = 1" = 20'  
 VERTICAL EXAGGERATION = 4x (1:4)  
 NOTE: LITHOLOGIC CONTACT LINES ARE INFERRED WHERE DASHED

Figure 2-1  
 Lithologic Cross Section A-A'  
 AOC 607 Phase III IM Work Plan  
 Charleston Naval Complex

NOTE: Original figure created in color

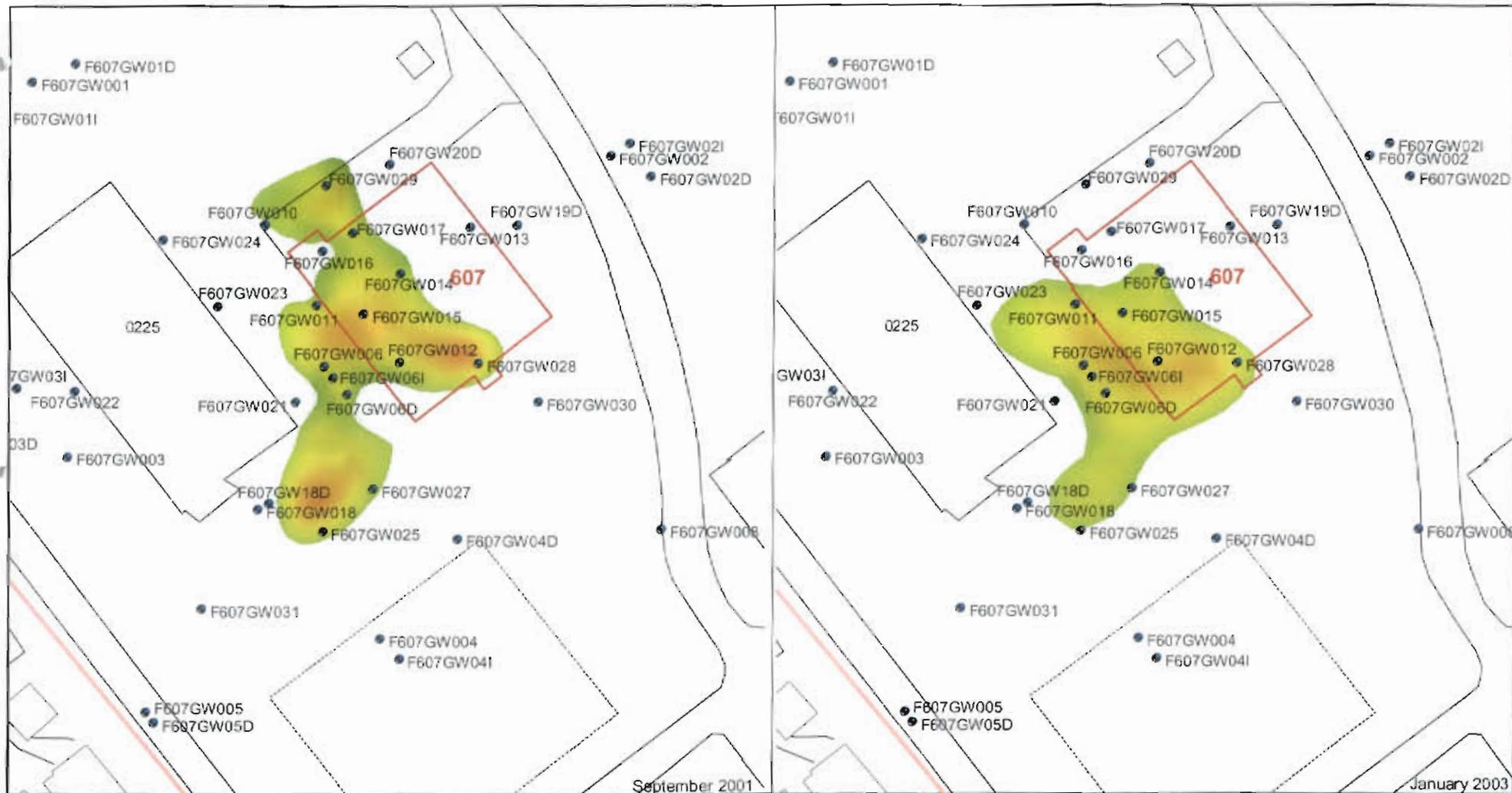


- Groundwater Well
- Buildings
- Zone Boundary
- ERH Target Treatment Boundary
- AOC Boundary
- Existing Fence
- Roads
- Pavement
- STORM-LINE
- SEWER-LINE



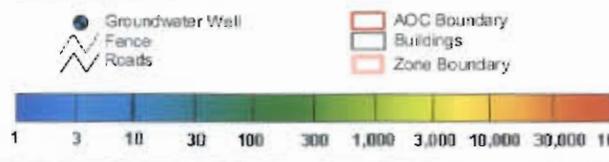
**Figure 2-2**  
 IM Groundwater Monitoring Locations  
 AOC 607, Zone F  
 Charleston Naval Complex

**CH2MHILL**



September 2001

January 2003



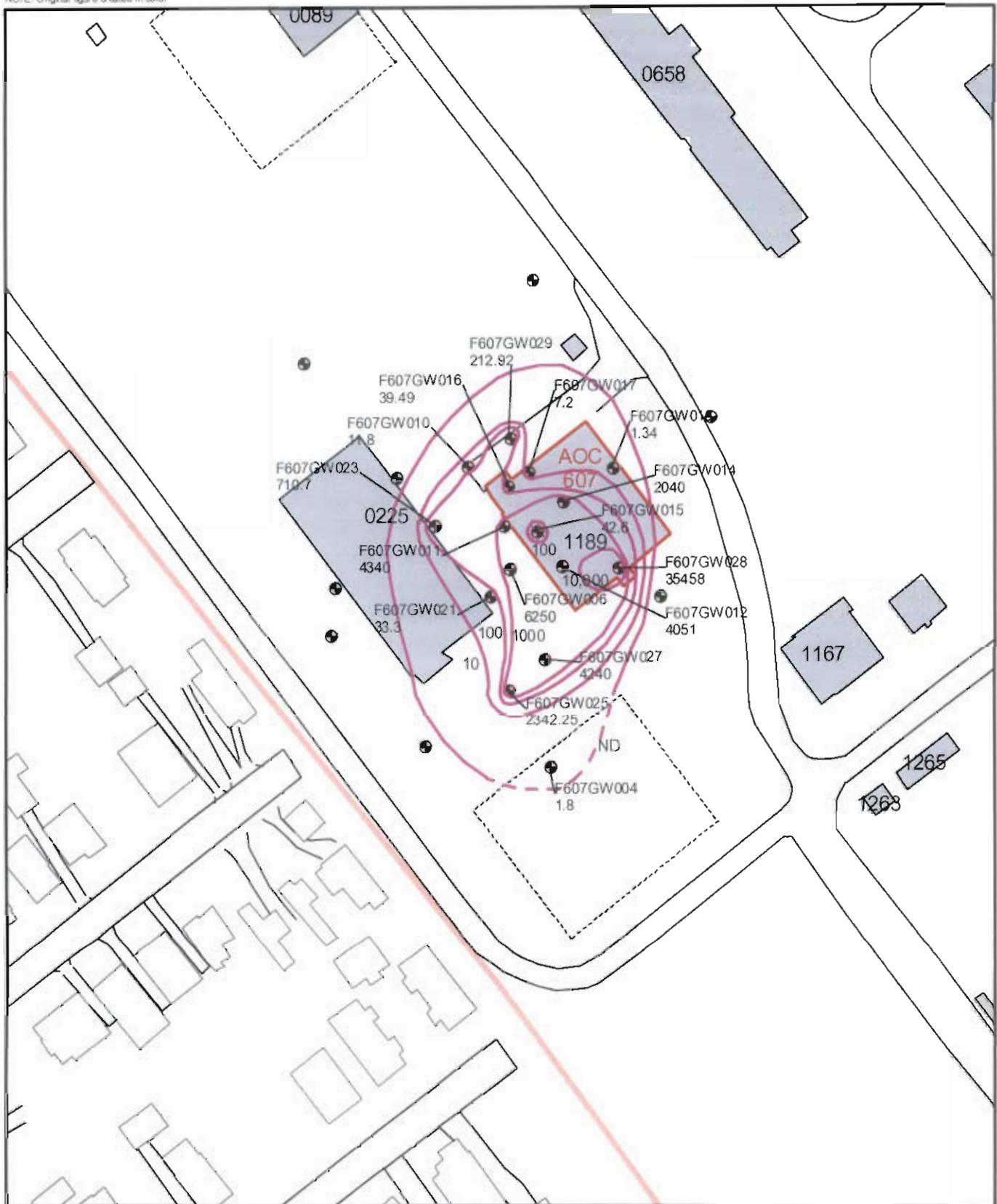
**Figure 2-3**  
 Total CVOCs Distribution - 3-D Plan View  
 September 2001 and January 2003  
 AOC 607, Zone F  
 Charleston Naval Complex

**CH2MHILL**

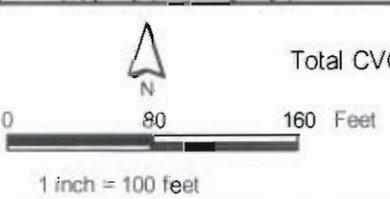
File Path: C:\11\figs\repro\docs\Fig\_2-3\007\figs\repro\figs\2-3\_007.dwg Date: 11 Apr 2003 8:11 User: MDC\JEB77 Figure 2-3 3-D Plan View - September 2001 and January 2003



NOTE: Original figure created in color



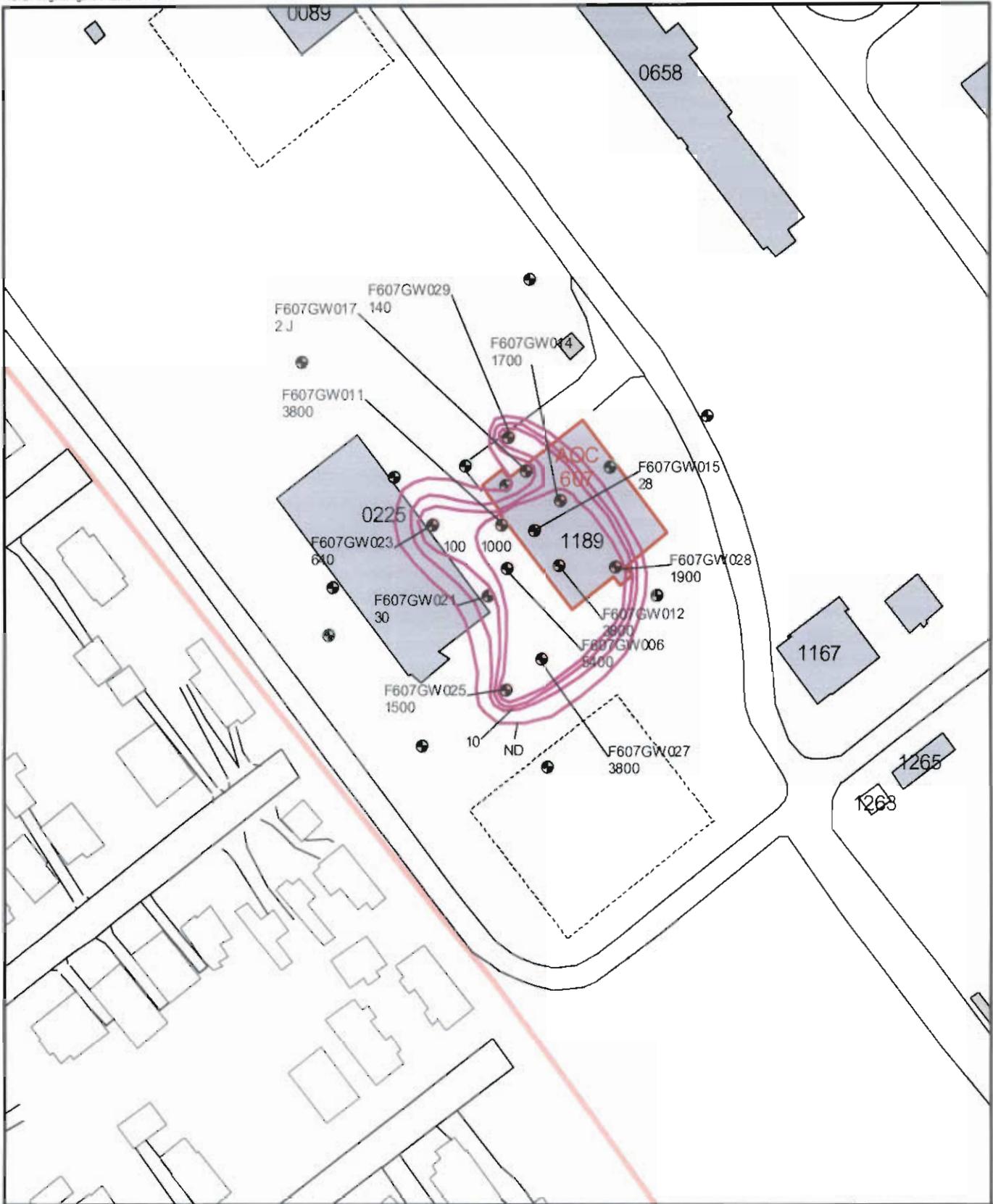
- Detect (Concentrations in ug/L)
- Non-Detect
- Known Isoconcentration Contour (ug/L)
- - - Inferred Isoconcentration Contour (ug/L)
- - - Fence
- Roads
- AOC Boundary
- Buildings
- Zone Boundary



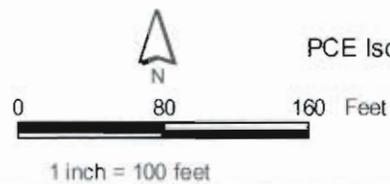
**Figure 2-5**  
 Total CVOC Isoconcentration Contours - January 2003  
 AOC 607, Zone F  
 Charleston Naval Complex



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**

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## 3.0 RAOs, Proposed MCSs, and Alternative Evaluation Criteria

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This section discusses the RAOs of this CMS and presents proposed MCSs for CVOCs in the shallow interval 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 parts.

### 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*

<b>Chemical</b>	<b>Proposed MCS (<math>\mu\text{g/L}</math>)</b>
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

$\mu\text{g/L}$     Micrograms per liter



## 1 **4.0 Description of Candidate Corrective** 2 **Measure Alternatives**

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3 This section identifies and describes the candidate corrective measure alternatives for  
4 addressing the COCs in groundwater at AOC 607. The groundwater contamination area  
5 targeted in this CMS is shown in Figures 2-5 and 2-6 in Section 2.0. This area of the CVOC  
6 plume to a depth of the clay layer approximately 10 to 11 ft bls is the focus of this CMS has  
7 VOC exceedances of the drinking water MCLs.

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

### 18 **4.1 Candidate Approaches for Preventing Contaminated** 19 **Groundwater Migration**

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

28 To date, significant migration of the plume away from the dry cleaner has not occurred. The  
29 most distal portion of the plume is less than approximately 200 feet from the dry cleaner.  
30 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 Figure  
4 3-1) shows a generally inward radial flow towards the sewer lines in this area of the site.  
5 Although such inward flow can occur due to natural conditions, such as downward flow  
6 into a lower aquifer unit, the data at AOC 607 suggest that the shallow groundwater is likely  
7 slowly discharging into the sanitary sewer.

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

11 Leading candidate alternatives for preventing migration of contaminated groundwater  
12 include:

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

15 In addition to these approaches, groundwater monitoring of perimeter wells is an ancillary  
16 technology that will be used to ensure that the selected containment approach is effective.  
17 The two leading candidate containment technologies are described in more detail below.

## 18 **4.1.1 Hydraulic Containment**

### 19 **Technology Description**

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

25 The groundwater recovery system removes contaminated groundwater from the affected  
26 aquifer and creates the necessary hydraulic gradients that prevent contaminated  
27 groundwater from migrating away from the groundwater collection area. Groundwater  
28 recovery can be achieved using vertical wells, collection trenches, or horizontal wells.

29 Because the size of the affected aquifer at AOC 607 is relatively small (less than 200 ft by 200  
30 ft) and groundwater to be recovered is shallow, a groundwater recovery system using  
31 conventional vertical recovery wells would likely be adequate for AOC 607.

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

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

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

### 13 **Key Uncertainties**

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

## 24 **4.1.2 Physical Containment**

### 25 **Technology Description**

26 Physical containment can be achieved using a variety of impermeable barriers. Commonly  
27 used barriers for containing contaminated groundwater plumes include slurry walls and  
28 sheet piling. These barriers prevent contaminated groundwater from migrating further by  
29 cutting off the migration flow paths in the aquifer. Typically these barriers are installed  
30 vertically into the aquifer around the area in which containment is desired. In some cases  
31 the barrier is installed completely around the contamination plume; in other cases it may  
32 only need to be installed partially around the plume. Importantly, the bottom of the barrier

1 must be installed into an aquitard underlying the area of containment. If an aquitard is not  
2 present, contaminated groundwater may flow beneath the barrier.

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

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

## 12 **Key Uncertainties**

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

### 18 **4.1.3 Selection of Presumptive Approach for Preventing Contaminated** 19 **Groundwater Migration**

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

## 24 **4.2 Candidate Approaches for Preventing Unacceptable** 25 **Exposures To Receptors**

26 The most viable approach to preventing unacceptable exposures of receptors to site COCs  
27 during the corrective measures period is via implementation of LUCs. A variety of LUCs are  
28 being implemented at the CNC, including restrictions on type of use (non-residential only),  
29 groundwater use restrictions, and digging restrictions. These LUCs could be effectively

1 applied at AOC 607 and achieve the objective of preventing unacceptable exposure to  
2 receptors. Few other methods are available that would be as effective as LUCs for achieving  
3 this objective. For this reason, LUCs are selected as the presumptive approach for  
4 preventing unacceptable exposure of COCs to receptors at the site.

## 5 **4.3 Candidate Approaches to Achieving Lower COC** 6 **Concentrations in Site Groundwater**

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

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

15 Detailed analyses of these technologies provide the rationale for selecting the recommended  
16 corrective measure alternative.

### 17 **4.3.1 Enhanced Reductive Dechlorination**

#### 18 **Technology Description**

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

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

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

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 microbia 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 are known to be capable of  
11 completing dechlorination to ethene (Major et al., 2001). Complete dechlorination has  
12 occurred at these sites when bioaugmentation with microbial cultures known to be capable  
13 of complete dechlorination has been employed. Bioaugmentation is considered potentially  
14 applicable in these special cases and can be evaluated through laboratory microcosm study  
15 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 achieved 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 (CO<sub>2</sub>) 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 (KMnO<sub>4</sub>) 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 (C<sub>2</sub>Cl<sub>4</sub>) by  
4 KMnO<sub>4</sub> is as follows:



6 Based on this stoichiometry, 1.3 grams (g) of KMnO<sub>4</sub> is needed to mineralize 1 g of TCE; 1 g  
7 of KMnO<sub>4</sub> produces approximately 0.55 g of MnO<sub>2</sub> solids.

8 KMnO<sub>4</sub> 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), KMnO<sub>4</sub> 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 KMnO<sub>4</sub> per kilogram (kg) of soil.

14 KMnO<sub>4</sub> dosages reported in technical literature range from approximately 0.1 to 20 g  
15 KMnO<sub>4</sub> 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, KMnO<sub>4</sub> reaction can limit the  
18 effective radius of treatment around an injection point, if the KMnO<sub>4</sub> 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 KMnO<sub>4</sub>  
24 dosage, with higher KMnO<sub>4</sub> 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 **4.2.3 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.

17



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

27 Typically lactate can sustain fermentation for approximately 10 to 45 days once injected. The  
28 length of time required between injections depends on a variety of site-specific factors. For  
29 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, temperature), VOCs, volatile fatty acids  
6 (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  $\text{KMnO}_4$  would involve injection of the material into injection  
29 wells in the vicinity of the five existing monitoring wells (F607GW006, F607GW011,  
30 F607GW012, F607GW027, and F607GW028), 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 shallow interval of the surficial aquifer to  
3 evaluate performance. The location of these proposed wells are depicted in Figure 5-1. The  
4  $\text{KMnO}_4$  application would be conducted in two events separated by approximately 3  
5 months of monitoring. This approach will allow real-time evaluation of the injection  
6 response, and subsequent adjustment of the injection plan for the second injection event.

7 The  $\text{KMnO}_4$  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  $\text{KMnO}_4$  would be delivered during each injection event.

12 The design concentration of  $\text{KMnO}_4$  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, 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 within the shallow interval of the surficial

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

1 magnitude level cost estimates are based on conceptual descriptions of the alternatives, not  
2 detailed design information. These estimates have an expected accuracy of -30 percent to  
3 +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, 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 within the shallow interval of the surficial  
26 aquifer would require greater than 95-percent reduction in concentration to meet their  
27 respective MCLs. This alternative may achieve a significant reduction in dissolved-phase  
28 VOC concentrations over 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
<b>Protection Of Human Health and the Environment</b>	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.
<b>Attainment of Media Cleanup Standards</b>	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.
<b>Control of the Source of Release</b>	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.
<b>Compliance with Applicable Waste Management Standards</b>	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.
<b>Long-Term Reliability and Effectiveness</b>			
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.
<b>Reduction of Toxicity, Mobility, or Volume of Wastes</b>			

**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

<b>Evaluation Criteria</b>	<b>Alternative 1: Hydraulic Containment, LUCs, and Enhanced Reductive Dechlorination</b>	<b>Alternative 2: Hydraulic Containment, LUCs, and In situ Chemical Oxidation</b>	<b>Alternative 3: Hydraulic Containment, LUCs and Monitored Natural Attenuation</b>
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 reductive dechlorination 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.
<b>Short-Term Effectiveness</b>			
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.
<b>(Short-Term Effectiveness)</b>			
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

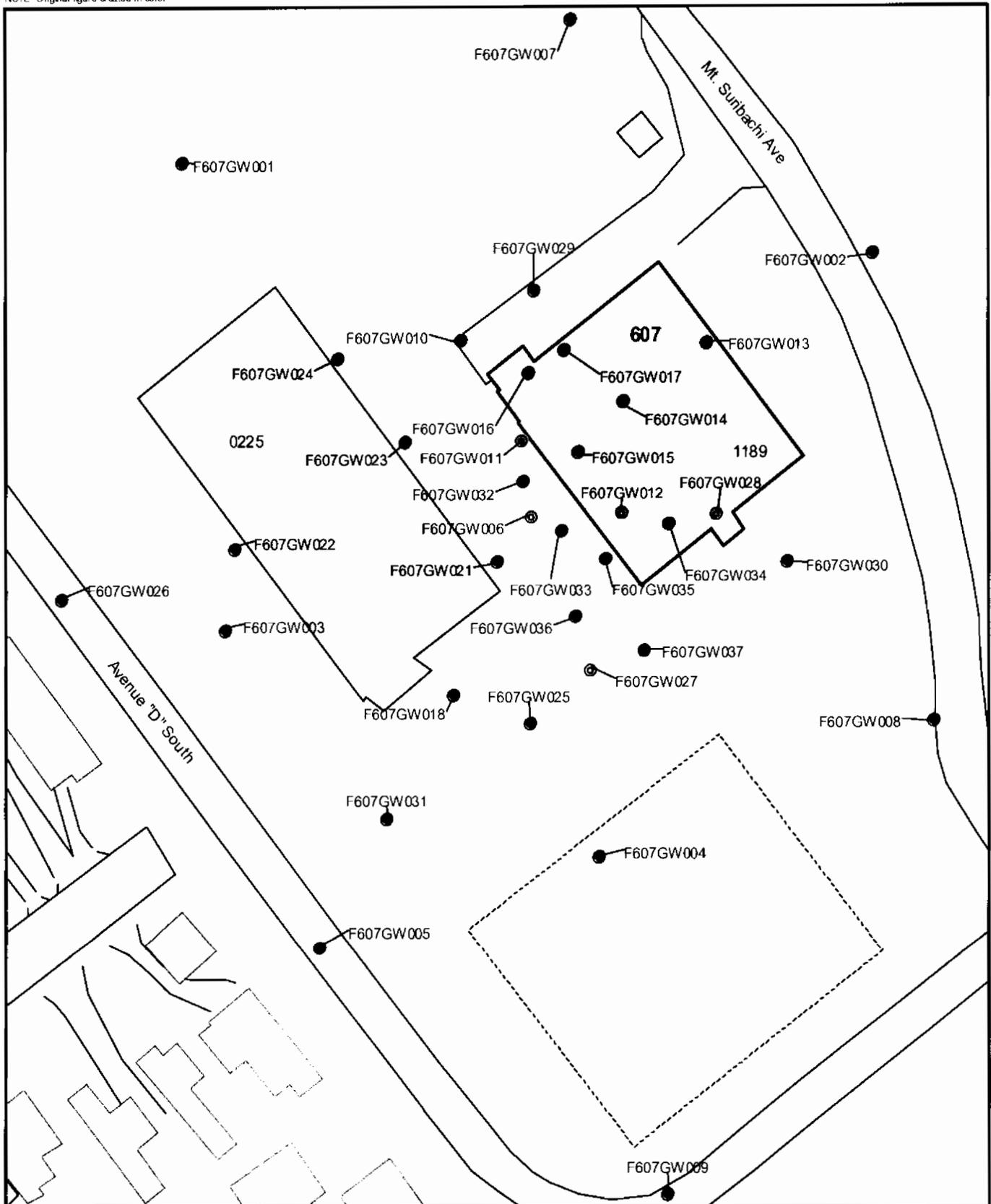
Evaluation Criteria	Alternative 1: Hydraulic Containment, LUCs, and Enhanced Reductive Dechlorination	Alternative 2: Hydraulic Containment, LUCs, and In situ Chemical Oxidation	Alternative 3: Hydraulic Containment, LUCs and Monitored Natural Attenuation
<b>Implementability</b>			
Technical Feasibility	High. Except for the new innovative analytical techniques. Process uses conventional and readily available technology.	High. Except for the new innovative analytical techniques. 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.
<b>Estimated Costs<sup>a</sup></b>			
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)
<b>Total Cost</b>	<b>\$490,000</b>	<b>\$464,000</b>	<b>\$410,000</b>

<sup>a</sup> Order-of-magnitude level cost estimates with expected accuracy of plus 50 to minus 30 percent.

<sup>b</sup> Assumes 3.2 percent discount rate, 5-year operation period, and annual sampling for 20 years.

<sup>c</sup> Assumes 3.2 percent discount rate and annual sampling for 20 years.

NOTE: Original figure created in color



● Existing Monitoring Well	□ AOC Boundary		<p>0      50      100 Feet</p> <p>1 inch = 58.3333 feet</p>
⊙ Injection Well	□ SWMU Boundary		
● Proposed Monitoring Well	□ Buildings		
--- Fence	□ Zone Boundary		
--- Railroads			
--- Roads			

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

**CH2MHILL**

**Section 6.0**

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## 1 **6.0 Recommended Corrective Measure** 2 **Alternative**

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3 Based on the preceding evaluation of available viable technologies and conditions at AOC  
4 607, a corrective measure approach employing hydraulic containment, LUCs, and ERD  
5 (Alternative 1) is recommended as the preferred alternative. This alternative will meet all of  
6 the RAOs established for the site and reduce contaminant mass and volume in localized  
7 areas of the shallow interval of the surficial aquifer. The ERD process is relatively easy to  
8 implement and cost effective when compared to ISCO using  $\text{KMnO}_4$ . It may provide for  
9 more substantial treatment of the residual plume compared to the other alternatives.

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

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



# 7.0 Enhanced In Situ Anaerobic Biodegradation Pilot Study Work Plan

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## 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 are 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  $\mu\text{g}/\text{L}$ , 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 Dehalococcoides. 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 **Groundwater Monitoring Procedures**

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

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

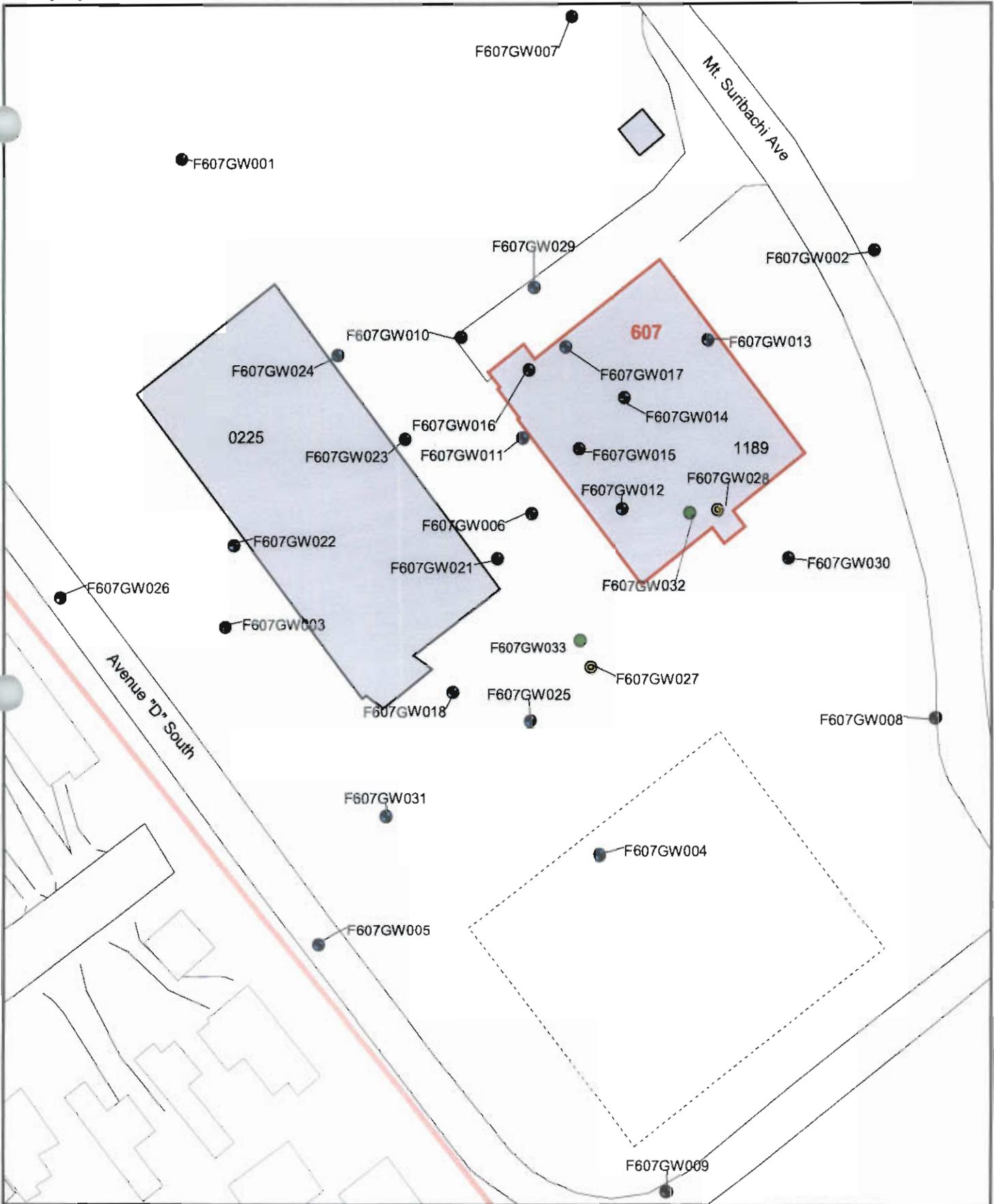
**TABLE 7-1**  
 Baseline Characterization Sampling and Analysis  
 Corrective Measures Study Report/Pilot Study Work Plan, AOC 607, Zone F, Charleston Naval Complex

Location	Media	Parameters
F607GW006	GW	VOCs
F607GW011	GW	VOCs
F607GW012	GW	VOCs
F607GW027	GW	VOCs, dissolved iron and manganese (field filtered), sulfate/sulfide, TOC, DHE (via Real Time PCR), PFLAs, alkalinity
F607GW028	GW	VOCs, dissolved iron and manganese (field filtered), sulfate/sulfide, TOC, DHE (via Real Time PCR), PFLAs, alkalinity
F607GW032	GW	VOCs, dissolved iron and manganese (field filtered), sulfate/sulfide, TOC, DHE (via Real Time PCR), PFLAs, VFAs, MEE, alkalinity
F607GW032	Soil (one sample collected from screened interval during well installation)	TOC, DHE (via Real Time PCR), PFLAs
F607GW033	GW	VOCs, dissolved iron and manganese (field filtered), sulfate/sulfide, TOC, DHE (via Real Time PCR), PFLAs, VFAs, MEE, alkalinity
F607GW033	Soil (one sample collected from screened interval during well installation)	TOC, DHE (via Real Time PCR), PFLAs

**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

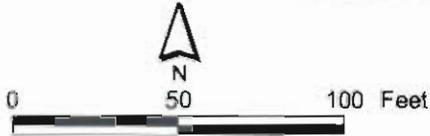
Parameter	Method	Sample Volume, Container, and Preservative
<b>A. Monthly Parameters</b>		
DO, ORP, pH, temperature, and specific conductance	Field	Standard field instruments
VOCs	SW846-8260B	3-40 ml VOA vial (Teflon lined cap), pH <2 HCl, cool to 4°C
Methane, ethane, and ethene (MEE)	SW8015M	2-40 ml 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
<b>B. Monthly Parameters</b>		
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



1 inch = 58.3333 feet

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





## 1 8.0 References

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## **Appendix A**

**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 $C_3H_7KO_3$ 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
<b>Total Project Duration (Years)</b>	20	20	20
<b>Capital Cost</b>	\$148,100	\$189,400	\$88,700
<b>Annual O&amp;M Cost</b>	\$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)
<b>Total Present Worth of Solution</b>	\$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 C<sub>3</sub>H<sub>5</sub>KO<sub>3</sub> 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
<b>SUBTOTAL</b>				<b>\$12,800</b>	
<b>Potassium Latate Injection</b>					Monthly injection events Assume 2000 gallons of lactate solution injected during each injection event.
Potassium Latate	600	LB	\$0.79	\$474	
Shipping - Potassium Latate Equipment	1	LS	\$200	\$200	600 pounds per drum
Lactate Mix System w/ one Tanks	1	EA	\$2,000	\$2,000	Two Injection Events Two weeks each
PPE Generator	12	Event	\$25	\$300	
Decon Equipment/Waste Handling Materials	1	EA	\$500	\$500	
Steam Cleaner	12	Event	\$75	\$900	
Miscellaneous Materials/Supplies	12	Event	\$50	\$600	
<b>Performance Monitoring</b>					
C <sub>3</sub> H <sub>5</sub> KO <sub>3</sub> Lab Sampling	12	Event	\$100	\$1,200	
C <sub>3</sub> H <sub>5</sub> KO <sub>3</sub> Lab Sampling	3	EA	\$4,530	\$13,590	Sample 6 Proposed Monitoring Wells, quarterly for first year
C <sub>3</sub> H <sub>5</sub> KO <sub>3</sub> Field Monitoring	9	EA	\$500	\$4,500	monthly for first year
<b>Labor</b>					
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	
<b>SUBTOTAL - Injection and Monitoring</b>				<b>\$38,304</b>	
<b>Hydraulic Containment - Groundwater Extraction</b>					
Land Use Controls	1	EA	\$52,100	\$52,100	
Land Use Controls	1	EA	\$5,000	\$5,000	
<b>SUBTOTAL</b>				<b>\$108,204</b>	
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	
<b>SUBTOTAL</b>				<b>\$128,763</b>	
Contingency	15%	of	\$128,763	\$19,314	
<b>TOTAL CAPITAL COST</b>				<b>\$148,100</b>	

Alternative 1:

**Enhanced In Situ Anaerobic Biodegradation using C<sub>3</sub>H<sub>5</sub>KO<sub>3</sub>****COST ESTIMATE SUMMARY**

10/10/2003

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
<b>Potassium Lactate Injection</b>					Monthly Injections Assume 2000 gallons per injection event
Potassium Lactate	600	LB	\$0.79	\$474	
Shipping - Potassium Lactate	1	LS	\$200	\$200	600 pounds per drum
<b>Equipment</b>					
PPE	12	Event	\$25	\$300	Monthly Injections
Decon Equipment/Waste Handling					
Materials	12	Event	\$75	\$900	
Miscellaneous Materials/Supplies	12	Event	\$100	\$1,200	
<b>Performance Monitoring</b>					
C <sub>3</sub> H <sub>5</sub> KO <sub>3</sub> Lab Sampling	3	EA	\$5,300	\$15,900	Sample 5 Existing and 6 Proposed Monitoring Wells
C <sub>3</sub> H <sub>5</sub> KO <sub>3</sub> Field Monitoring	6	EA	\$500	\$3,000	
<b>Labor</b>					
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	
<b>SUBTOTAL - Injection and Monitoring</b>				<b>\$36,014</b>	
<b>Hydraulic Containment - Groundwater Extraction</b>					
Land Use Controls	1	EA	\$12,000	\$12,000	
Land Use Controls	1	EA	\$1,100	\$1,100	
<b>Annual Report</b>					
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	
<b>SUBTOTAL - Annual Report</b>				<b>\$5,220</b>	
<b>TOTAL ANNUAL O&amp;M COST</b>				<b>\$54,000</b>	

**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
<b>TOTAL PRESENT WORTH OF ALTERNATIVE</b>				<b>\$490,000</b>	

**SOURCE INFORMATION**

## Alternative 2: In-Situ Chemical Oxidation using KMnO4

## COST ESTIMATE SUMMARY

Site: Charleston Naval Complex  
 Location: AOC 607  
 Purpose: 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
<b>SUBTOTAL</b>				<b>\$13,300</b>	
<b>Potassium Permanganate Injection</b>					Two injection events separated by 3 months Assume 14,000 gallons of 3% KMnO <sub>4</sub> injected solution during each injection event. 3,142 pounds of KMnO <sub>4</sub> 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 <sub>4</sub> 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	
<b>Performance Monitoring</b>					
KMnO <sub>4</sub> Lab Sampling	3	EA	\$5,800	\$17,400	Sample 5 Existing and 6 Proposed Monitoring Wells
KMnO <sub>4</sub> 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	
<b>SUBTOTAL - Injection and Monitoring</b>				<b>\$67,983</b>	
<b>Hydraulic Containment - Groundwater Extraction Land Use Controls</b>					
	1	EA	\$52,100	\$52,100	
	1	EA	\$5,000	\$5,000	
<b>SUBTOTAL</b>				<b>\$138,383</b>	
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	
<b>SUBTOTAL</b>				<b>\$164,676</b>	
Contingency	15%	of	\$164,676	\$24,701	
<b>TOTAL CAPITAL COST</b>				<b>\$189,400</b>	

Site: Charleston Naval Complex  
 Location: AOC 607  
 Project: Corrective Measures Study  
 Estimate 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
<b>Potassium Permanganate Injection</b>					
Potassium Permanganate	0	LB	\$1.35	\$0	Two injection events separated by 6 months Assume 14,000 gallons of 3% KMnO <sub>4</sub> injected solution during each injection event. 3,142 pounds of KMnO <sub>4</sub> 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 <sub>4</sub> Lab Sampling	0	EA	\$5,800	\$0	Sample 5 Existing and 6 Proposed Monitoring Wells
KMnO <sub>4</sub> 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	
<b>SUBTOTAL - Injection and Monitoring</b>				<b>\$0</b>	
<b>Hydraulic Containment - Groundwater Extraction</b>	1	EA	\$12,000	\$12,000	
<b>Land Use Controls</b>	1	EA	\$1,100	\$1,100	
<b>Annual Report</b>					
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	
<b>SUBTOTAL - Annual Report</b>				<b>\$0</b>	
<b>TOTAL ANNUAL O&amp;M COST</b>				<b>\$13,000</b>	

**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
<b>TOTAL PRESENT WORTH OF ALTERNATIVE</b>				<b>\$463,994</b>	
				<b>\$464,000</b>	

**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	1	EA	\$0	\$0	No Monitoring Well Installation - Use Existing Network
Monitoring/Natural Attenuation Work Plan					
Groundwater Contingency Plan					
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
<b>SUBTOTAL</b>				<b>\$17,380</b>	
<b>Hydraulic Containment - Groundwater Extraction</b>	1	EA	\$52,100	\$52,100	
<b>Land Use Controls</b>	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	
<b>SUBTOTAL</b>				<b>\$77,087</b>	
Contingency	15%	of	\$77,087	\$11,563	
<b>TOTAL CAPITAL COST</b>				<b>\$88,700</b>	

**OPERATIONS AND MAINTENANCE COST**

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Annual Groundwater Sample Collection Event	1	EA	\$10,200	\$10,200	
<b>Hydraulic Containment - Groundwater Extraction</b>	1	EA	\$12,000	\$12,000	
<b>Land Use Controls</b>	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	
<b>SUBTOTAL</b>				<b>\$28,520</b>	
<b>TOTAL ANNUAL O&amp;M COST</b>				<b>\$29,000</b>	

**Alternative 3: Monitoring/Natural Attenuation** **COST ESTIMATE SUMMARY** NOV2003

**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	
<b>TOTAL PRESENT WORTH OF ALTERNATIVE</b>				<b>\$410,000</b>	

**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).