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Final  
SWMU 2C Ground Water Investigation Report  
Oceana Naval Air Station  
Virginia Beach, Virginia



Prepared for

**Department of the Navy**  
**Atlantic Division**  
**Naval Facilities Engineering Command**

Contract No. N62470-95-D-6007  
CTO-0124

February 2001

Prepared by

**CH2MHILL**

**Baker**  
Environmental, Inc.

**CDM**  
Federal Programs Corp.

03.15-2/1/01-00555

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# 1.0 Introduction

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This report presents the results of a ground water quality investigation for the Solid Waste Management Unit #2C (SWMU 2C) located at Naval Air Station (NAS) Oceana in Virginia Beach, Virginia. The purpose of this investigation was to delineate the horizontal and vertical extent of the chlorinated solvent contamination in groundwater at the SWMU. The contaminants of specific concern are trichloroethene (TCE) and its daughter products *cis*-1,2-dichloroethylene (*cis*-1,2-DCE) and vinyl chloride. To achieve this objective, both conventional and direct-push technology (DPT) sampling methods were utilized during this investigation. The field work was conducted during late January through early March 2000 with a follow-on vertical profiling investigation in July 2000.

The scope of work for this sampling event is documented in the *Draft Work Plan, Direct Push Technology Investigation, Supplemental Activities, SWMU 2C, Naval Air Station, Oceana, Virginia Beach, Virginia*. CH2M HILL dated November 1999. The Tier 1 Partnering Team reviewed the plan and consensus was reached to move ahead in the November 1999 meeting.

The specific objectives of the ground water investigation were to: (1) sample select monitoring wells at SWMU 2C and analyze the samples in a close-support laboratory (CSL) to guide the DPT investigation; (2) sample groundwater from the water-table aquifer using DPT and analyze groundwater sample results in the CSL to delineate the nature and extent of chlorinated VOC groundwater contamination at SWMU 2C; (3) present the interim investigation results to the NAS Oceana partnering team; (4) assess the correlation between DPT groundwater sampling results and vertical profiling results to determine the effectiveness of vertical profiling for characterizing chlorinated compound contamination, and (5) prepare a draft-final and final report presenting the results of the investigation with recommendations for application of innovative remedial technologies and the potential effectiveness of long-term monitoring.

Historical background information for SWMU 2C is documented in the following reports:

CH2M HILL, December 1993, *RCRA Facility Investigation Final Report – Phase I, Naval Air Station Oceana, Virginia Beach, Virginia*,

CH2M HILL, November 1995, *Draft Final Corrective Measures Study for SWMUs 1, 2B, and 2C, Oceana Naval Air Station, Virginia Beach, Virginia*.

This report is divided into nine sections. Section 1 provides an introduction to SWMU 2C and presents the objectives of the investigation. Section 2 summarizes the hydrogeology of the SWMU. Section 3 documents the methods for the low-flow monitoring well groundwater sampling. Section 4 summarizes the methods and results for the monitoring well and DPT groundwater sampling at SWMU 2C. Section 5 documents the results of vertical profiling. Section 6 provides a summary of natural attenuation. Section 7 provides an assessment of remedial options. Section 8 provides the conclusion for this investigation and documents recommendations for future activities at SWMU 2C. Finally, Section 9 provides references.

## 2.0 SWMU 2C Hydrogeology

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### 2.1 Stratigraphy

NAS Oceana is located in the outer Atlantic Coastal Plain Physiographic Province, which is characterized by low elevations and gently sloping relief. The Station is underlain by more than 2,000 feet of gently dipping sandy sediment, ranging in age from Recent to Lower Cretaceous.

The uppermost geologic unit is the Columbia Group, composed of the Sand Bridge Formation and the underlying Norfolk Formation. The Columbia Group is approximately 60 feet thick. The upper 20 to 40 feet consist of unconsolidated fine sands and silts of low to moderate permeability. The lower 20 to 40 feet consist of relatively impermeable silt, clay, and sandy clay. The Yorktown Formation underlies the Columbia Group. The Yorktown Formation is approximately 90 to 100 feet thick in the vicinity of the Station. It consists of moderately consolidated coarse sand and gravel with abundant shell fragments.

Two significant aquifer systems in the area are the water-table aquifer in the upper 20 to 40 feet of the Columbia Group and the underlying Yorktown Aquifer. The water-table aquifer reportedly consists of discontinuous and heterogeneous sand and shell lenses. The depth to the water table is usually less than 3-7 feet. The Yorktown Aquifer is semi-confined beneath a clay layer in the upper Yorktown Formation. Water-bearing zones in the Yorktown Aquifer consist of fine to coarse sand, gravel, and shells.

SWMU 2C is located on the flight line at the center of NAS Oceana (Figure 2-1). The lithology at SWMU 2C has been determined by soil logging during the installation of monitoring wells. According to monitoring well logs from SWMU 2C the uppermost 5 to 6 feet of the Columbia Group is composed of clay-rich silt interbedded with discontinuous lenses of fine-grained sand. At approximately 5 to 6 feet below ground surface, the silt grades into a fine to medium-grained sand. The sandy section is generally medium-grained at the top and grades into a fine-grained sand, interbedded with discontinuous thin stringers of silt.

The bottom of the sandy section, between depths of 18 and 23 feet, is generally medium grained. At a depth of approximately 23 feet the medium-grained sand grades abruptly into a silty clay with interbedded fine sand. The silty clay continues to depths greater than 30 feet.

### 2.2 Hydrogeology

In general the Columbia Aquifer at SWMU 2C is composed of the fine to medium grained sand at depths from approximately 6 to 20 feet below ground surface. The aquifer is semi confined between clay rich silt in the uppermost 6 feet and at depths below approximately 20 feet. The lower confining unit is known to extend to depths of approximately 60 feet and separates the Columbia Aquifer from the underlying Yorktown Aquifer.

Water level elevations were measured from each monitoring well prior to sampling to gather data to construct a water table elevation map. A water table map produced from these measurements illustrates a ground water flow direction which varies from south to southwesterly across the SWMU (Figure 2-2). This flow direction is consistent with historic water table elevation studies at this SWMU. The water table elevations depicted in this figure represent a period of time when abundant precipitation raised the water table to an elevation close to or above ground surface at some locations on the Station. The February water table map indicates a south-south-westerly directed groundwater flow direction across the SWMU. Historic water level data are tabulated in Table 2-1.

The groundwater velocity at the SWMU is consistent with velocities calculated at other SWMUs at NAS Oceana. The most recent study, at SWMU 15, indicated a groundwater velocity range of 3 to 24 feet per year in the Columbia Aquifer depending on depth and lithology. The average groundwater velocity for the sand unit comprising the Columbia Aquifer at SWMU 15 was determined to be approximately 10 feet per year. SWMU 2C is about 5000 feet hydraulically downgradient of SWMU 15.

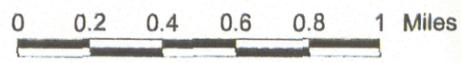
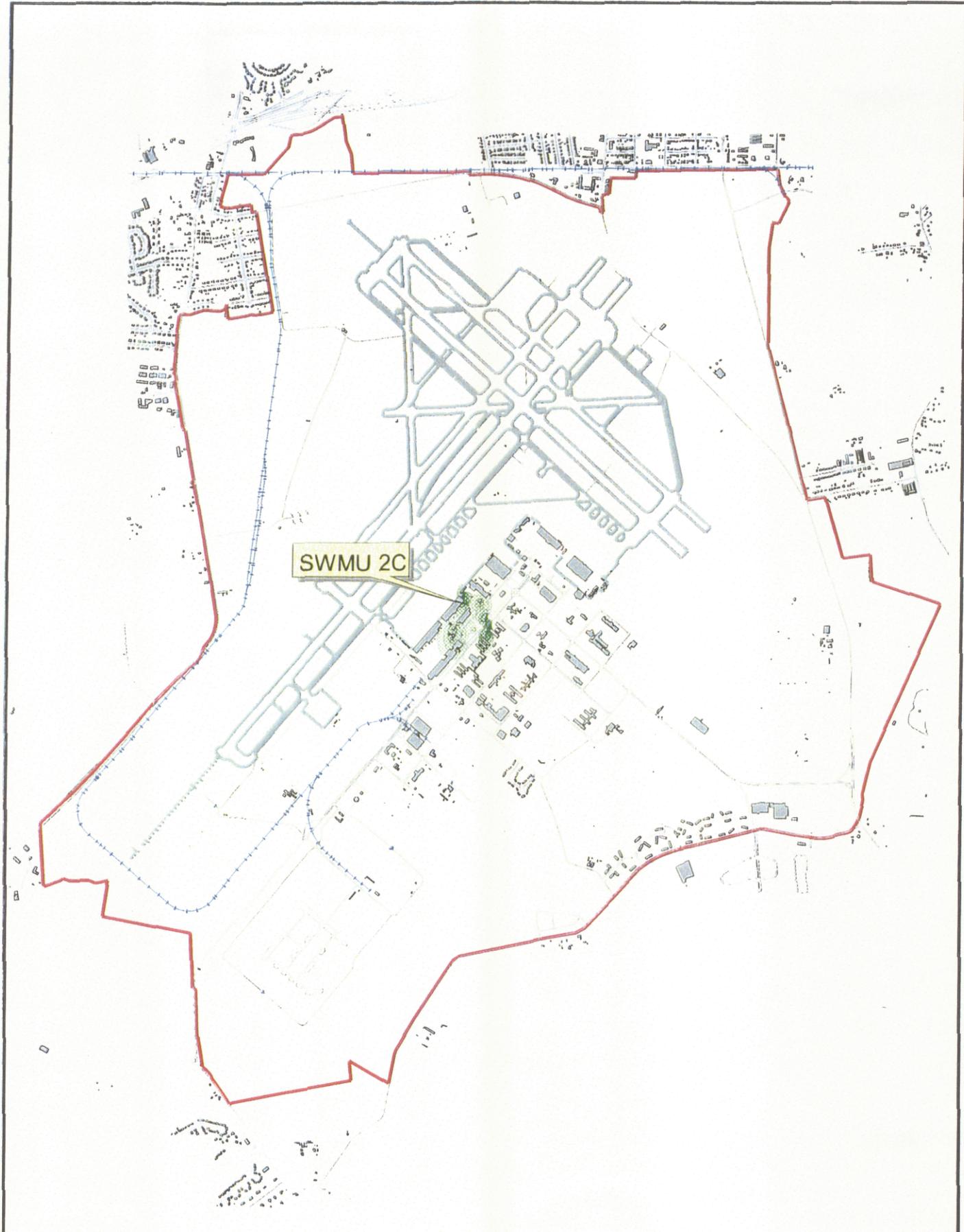


Figure 2-1  
SWMU 2C Location Map  
NAS Oceana, Virginia Beach, Virginia

**CH2M HILL**

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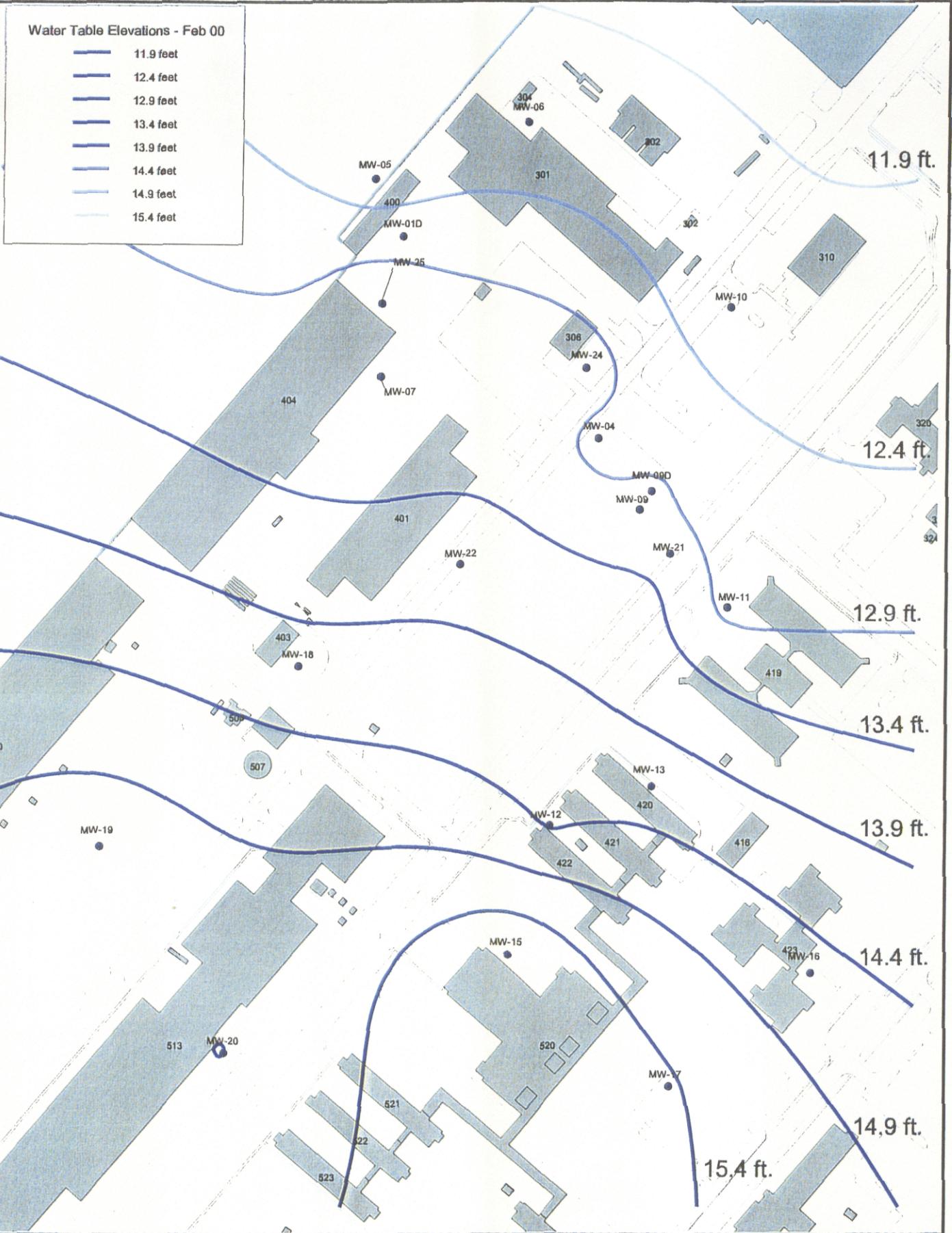


Figure 2-2  
Water Table Elevation Map, February 2000 - SWMU 2C  
NAS Oceana, Virginia Beach, Virginia

Table 2-1  
Historic Water Level Data and Well Status - SWMU 2C

Well	Date Installed	Measuring Point Elevation (ft above MSL)	Ground Surface Elevation (ft above MSL)	Total Depth (ft)	Screened Interval (ft BGS)	Water-Table Elevation (ft)						Comments
						Sep-88	Nov-90	Feb-93	Mar-94	May-94	Jan-00	
2C-MW1	9/13/88	20.46	20.5	20	10 - 20	12.7	12.37	13.62	15.04	13.25	-	Removed
2C-MW1D	12/17/92	20.43	20.43	62	45 - 55	-	-	13.54	14.83	13.03	14.63	
2C-MW2	9/9/88	20.52	20.8	20	10 - 20	12.49	12.25	13.47	14.94	13.02	-	Removed
2C-MW3	9/9/88	21.29	20	18	8 - 18	12.47	12.04	13.54	-	-	-	Abandoned
2C-MW4	9/14/88	19.56	17	18	8 - 18	12.11	11.75	13.22	14.58	12.56	14.59	
2C-MW5	7/12/90	20.42	20.4	16	6 - 16	-	12.52	13.79	15.08	13.45	15.17	
2C-MW6	6/29/90	23.18	20.7	21	11 - 21	-	12.61	13.92	15.24	143.5	15.18	
2C-MW7	7/5/90	20.81	20.8	19	9 - 19	-	12.01	13.4	14.81	12.9	14.61	
2C-MW8	7/3/90	19.05	19	17	7 - 17	-	11.76	13.14	14.63	-	-	Removed
2C-MW9	7/3/90	19.33	17	17.5	7.5 - 17.5	-	12.61	12.99	14.27	12.26	14.38	
2C-MW9D	12/15/92	19.45	17.1	57	42 - 52	-	-	12.89	14.11	12.29	14.3	
2C-MW10	12/10/92	18.24	18.24	20	10 - 20	-	-	13.59	14.88	12.99	15.2+	
2C-MW11	12/9/92	18.47	18.47	23	13 - 23	-	-	12.53	13.69	11.95	14.52	
2C-MW12	12/9/92	17.84	17.84	23	13 - 23	-	-	11.72	12.98	11.29	12.94	
2C-MW13	12/11/92	18.49	18.49	21	11 - 21	-	-	11.76	12.86	11.29	13.09	
2C-MW14	3/1/94	19.47	19.5	24	10 - 20	-	-	-	14.79	12.83	-	Removed
2C-MW15	2/28/94	18.24	18.2	24	10 - 20	-	-	-	8.32	10.84	11.44	
2C-MW16	2/25/94	18.84	18.8	24	10 - 20	-	-	-	12.4	11.02	12.74	
2C-MW17	3/3/94	18.35	18.4	20	10 - 20	-	-	-	11.58	10.39	11.85	
2C-MW18	3/8/94	18.25	18.2	19	9 - 19	-	-	-	14.04	12.05	13.25	
2C-MW19	5/9/94	20.56	20.6	20	9 - 19	-	-	-	-	11.3	12.06	
2C-MW20	5/10/94	19.42	19.4	20	10 - 20	-	-	-	-	11.07	12.42	
2C-MW21	7/29/99	17.14	17.39	18	3 - 18	-	-	-	-	-	13.74	
2C-MW22	8/31/99	17.96	18.21	18	3 - 18	-	-	-	-	-	13.56	
2C-MW23	9/1/99	19.05	19.37	18	3 - 18	-	-	-	-	-	14.05	
2C-MW24	9/1/99	18.45	18.72	18	3 - 18	-	-	-	-	-	14.05	
2C-MW25	8/31/99	20.28	20.49	18	3 - 18	-	-	-	-	-	13.98	

## 3.0 Monitoring Well Ground Water Sampling

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During February 2000, ground water samples were collected from twenty groundwater monitoring wells at SWMU 2C. The monitoring well ground water sampling locations are illustrated in Figure 3-1. The ground water sampling activities at SWMU 2C were conducted by Columbia Technologies under a subcontract to CH2M HILL. The purpose of the groundwater sampling was to provide a baseline from which to proceed with subsequent DPT groundwater sampling. The ground water analytical data were generated in an on-site close support laboratory (CSL). The monitoring well groundwater analytical results provided an estimation of the horizontal extent of the VOC contamination derived from widely spaced monitoring wells.

All ground water samples were collected using a low-flow peristaltic pump with dedicated tubing in accordance with CH2M HILL, Inc.'s standard operating procedures (SOPs) for ground water sampling.

Upon collection, all ground water samples were submitted to the CSL for analysis of Target Compound List (TCL) Low-concentration (LC) Volatile Organic Compounds (VOCs). These analyses were utilized to establish baseline data for monitoring well groundwater. Natural attenuation parameters were collected in the field and analyzed in the CSL or by field meter. These parameters included ferrous iron, nitrate, sulfate/sulfide, chloride, methane, ethane, ethene, TOC, and alkalinity. In addition, dissolved oxygen, pH, Eh, specific conductance, and temperature were measured in the field utilizing a flow through cell. These parameters were measured several times during purging activities to ensure that the sample was as representative as possible of naturally occurring conditions. The CSL monitoring well groundwater quality results were validated for use in risk assessment.

The results of groundwater sampling of monitoring wells indicated a widespread groundwater contaminant plume of vinyl chloride with two areas of significant elevation in concentrations one in the area of MW25 and the other in the area of MW21. Trichloroethene (TCE) and cis-1,2-dichloroethene (cis-1,2-DCE) were also detected in the two areas with elevated vinyl chloride concentrations. Since the monitoring wells are screened across the stratigraphic interval that was sampled during direct push sampling the monitoring well and DPT data were combined for spatial analysis. No significant disparity between the two data sets was noted.

Therefore, monitoring well groundwater sampling results are included in the summary of DPT sampling results and are documented in the next section.



Figure 3-1  
Monitoring Well Locations - SWMU 2C  
NAS Oceana, Virginia Beach, Virginia

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## 4.0 SWMU 2C Plume Delineation

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CH2M HILL conducted a DPT ground water investigation at SWMU 2C to define the horizontal and vertical extent of the VOC contaminant plume in order to support a decision regarding the need for ground water remediation. The DPT ground water samples were analyzed on site using the CSL. Concurrently, DPT ground water samples were collected from ninety-seven DPT-installed piezometers using standard low-flow ground water sampling techniques. Procedures and results of the DPT investigation are documented below.

### 4.1 DPT Sampling Procedures

DPT groundwater sampling was used to identify the overall size of the chlorinated VOC contaminant plume in groundwater and to delineate two hotspots for potential innovative chlorinated volatile reduction. DPT sample locations are depicted in Figure 4-1.

A total of 108 DPT groundwater samples were collected from 97 piezometer locations to define the overall extent of the contaminant plume. The initial sampling locations were based on the analytical results from monitoring well sampling at SWMU 2C and the sample locations were sited on an iterative basis depending upon analytical results that were produced by the CSL on a day-to-day basis during the investigation.

Two areas of elevated chlorinated hydrocarbon contamination were identified during monitoring well sampling. These areas were identified for detailed delineation to support potential remedial designs. For elevated area delineation two grids, each measuring approximately 100-foot by 100-foot with 20-foot sampling node spacing, were completed for the vicinity of the contaminated areas around MW25 and MW21. The sampling grid was modified in the field based on the CSL analytical results and site conditions.

The initial DPT sampling locations began in the vicinity of known elevated chlorinated-VOC concentrations at MW21. To delineate the vertical extent of the contamination plume, three groundwater samples were collected at each DPT location in a transect from upgradient locations thru downgradient locations of MW21; one near the top of the surficial aquifer (3 feet deep), one near the center of the surficial aquifer (9 feet deep), and one near the bottom of the surficial aquifer (15 feet deep). The sample interval was a 5-foot screen with the depth noted being the depth at the top of the screen. Therefore, the deepest sample interval of 15 to 20 feet produced a sample collected from the base of the aquifer with the top of the silt and clay confining unit occurring at a depth of 20 feet bgs. Based on the analytical results from the CSL, the stratigraphic interval with most elevated level of chlorinated VOCs was sampled laterally to delineate the horizontal extent of the contaminant plume.

The DPT groundwater samples were analyzed by an on-site CSL. The analytical protocol for the groundwater samples included TCL VOCs including TCE, *cis*-1,2-DCE, and vinyl chloride. Natural attenuation parameters were collected in the field and analyzed in the

CSL or by a field meter. These parameters included ferrous iron, nitrate, sulfate/sulfide, chloride, methane, ethane, ethene, TOC, and alkalinity). In addition, dissolved oxygen, pH, Eh, specific conductance, and temperature were measured in the field utilizing a flow-through cell. These parameters were measured several times during purging activities to ensure that the sample was as representative as possible of naturally occurring conditions.

## 4.2 Results of the DPT Sampling

Table 4-1 lists the chemicals detected in DPT groundwater, the frequency of detection, the maximum concentration detected, the location of the maximum concentration, the mean value, the standard deviation, and the MCL. The primary contaminants of concern are TCE and its daughter products *cis*-1,2-DCE, and vinyl chloride. All of these chemicals were detected in groundwater at levels greater than the MCL. Benzene was also detected in groundwater at levels greater than the MCL. Detected compounds in monitoring well groundwater samples are tabulated in Appendix A-1. Detected compounds in DPT groundwater samples are tabulated in Appendix A-2.

Results of DPT sampling indicate that there are two areas of elevated chlorinated hydrocarbon contamination in groundwater. The area of greatest concentrations is in the southern part of the SWMU near MW21. Multiple depth groundwater sampling at locations DW01 through DW03 indicated that the optimum depth for sampling around this area was the interval from 15 to 20 feet below ground surface (bgs) as samples from this depth interval yielded the highest detected values of chlorinated hydrocarbons. A smaller size area with lower chlorinated hydrocarbon contamination is located in the northern part of the SWMU near MW25. Multiple depth groundwater sampling at locations DW04 through DW06 indicated that the optimum depth for sampling around this area was the interval from 9 to 13 feet bgs as samples from this depth interval yielded the highest detected values of chlorinated hydrocarbons.

Figure 4-2 depicts the distribution of TCE detected in direct push and monitoring well groundwater. The highest detected TCE concentration is 37 ug/L at sample location DW97 at a depth of 15 feet. The TCE groundwater contamination is located in the southernmost elevated area around MW21 but is absent from the MW25 area. The plume seems to originate near MW9 and MW9D and it extends southerly in the direction of groundwater flow.

Figure 4-3 depicts the distribution of *cis*-1,2-DCE detected in direct push and monitoring well groundwater. The highest detected *cis*-1,2-DCE concentration is 676 ug/L at sample location DW01 at a depth of 15 feet. The groundwater contamination is located in both the northern area around MW25 and the southern area around MW21. In the northern area the plume seems to originate near the northeastern wall of building 404. In the southern area, the plume has higher concentrations and seems to originate near MW9 and MW9D and it extends southerly in the direction of groundwater flow, similarly to the TCE plume.

Figure 4-4 depicts the distribution of vinyl chloride detected in direct push and monitoring well groundwater. The highest detected vinyl chloride concentration is 897 ug/L at sample location DW30 at a depth of 15 feet. The vinyl chloride groundwater contamination is located in both the northern area around MW25 and the southern area around MW21. In

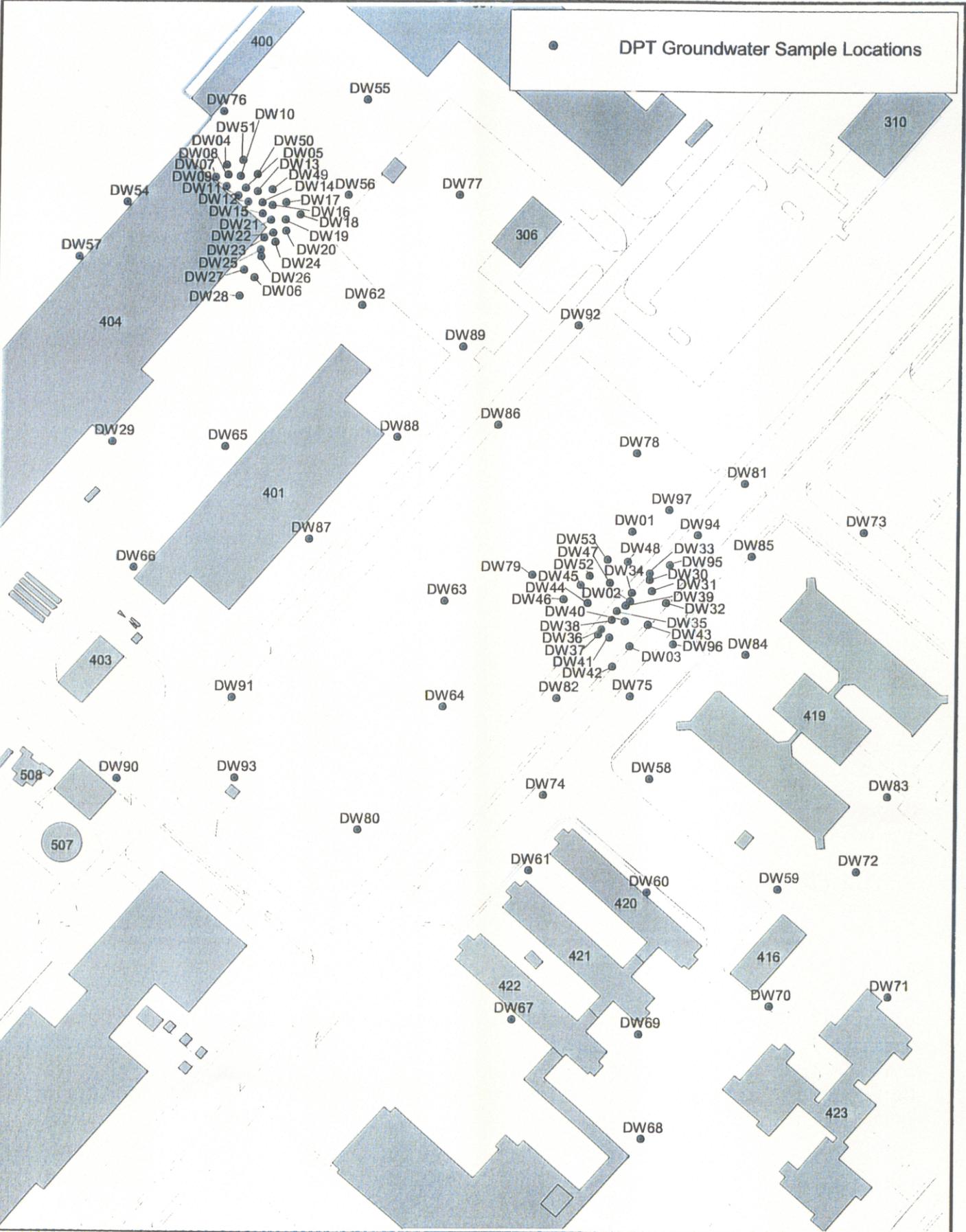


Figure 4-1  
DPT Locations - SWMU 2C  
NAS Oceana, Virginia Beach, Virginia

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## Statistics on Groundwater Sample Results - SWMU 2C

AnalyteName	Detection Frequency	Maximum Detected Concentration	SampleID of Maximum Detected Value	Mean Value (Norm)	Standard Deviation (Norm)	MCL (ug/L)	Exceeds MCL?
<b>Volatile Organic Compounds (UG/L)</b>							
1,1,2-TRICHLOROETHANE	1 - 116	1.7	OW2C-DW76-15	1.17	1.76	5	
1,1-DICHLOROETHANE	76 - 116	76	OW2C-DW13-09	4.47	9.20	999999	
1,1-DICHLOROETHENE	9 - 116	3.1	OW2C-DW81-15	1.21	1.78	7	
1,2,4-TRICHLOROBENZENE	2 - 116	0.8	OW2C-DW67-15	1.16	1.76	70	
1,2-DICHLOROBENZENE	5 - 116	3	OW2C-DW45-15	1.21	1.78	600	
1,4-DICHLOROBENZENE	1 - 116	0.9	OW2C-DW26-09	1.16	1.76	75	
BENZENE	27 - 116	33	OW2C-DW87-15	2.05	4.36	5	Yes
BROMOFORM	5 - 116	1.5	OW2C-DW67-15	1.18	1.76	100	
CHLOROENZENE	8 - 116	1.8	OW2C-DW24-09	1.19	1.77	100	
CHLOROETHANE	6 - 116	4.7	OW2C-DW36-15	1.29	1.85	999999	
CHLOROFORM	1 - 116	27	OW2C-DW49-09	1.39	2.98	100	
CIS-1,2-DICHLOROETHENE	86 - 116	676	OW2C-DW01-15	42.84	97.20	70	Yes
METHYLENE CHLORIDE	4 - 116	2.6	OW2C-DW70-15	1.19	1.77	5	
O-XYLENE	4 - 116	1.9	OW2C-DW13-09	1.19	1.77	999999	
TOLUENE	8 - 116	17	OW2C-DW13-09	2.00	3.03	1000	
TRANS-1,2-DICHLOROETHENE	45 - 116	18	OW2C-DW51-09	2.97	3.87	100	
TRICHLOROETHENE	50 - 116	37	OW2C-DW97-15	3.65	5.31	5	Yes
VINYL CHLORIDE	99 - 116	897	OW2C-DW30-15	125.93	189.19	2	Yes

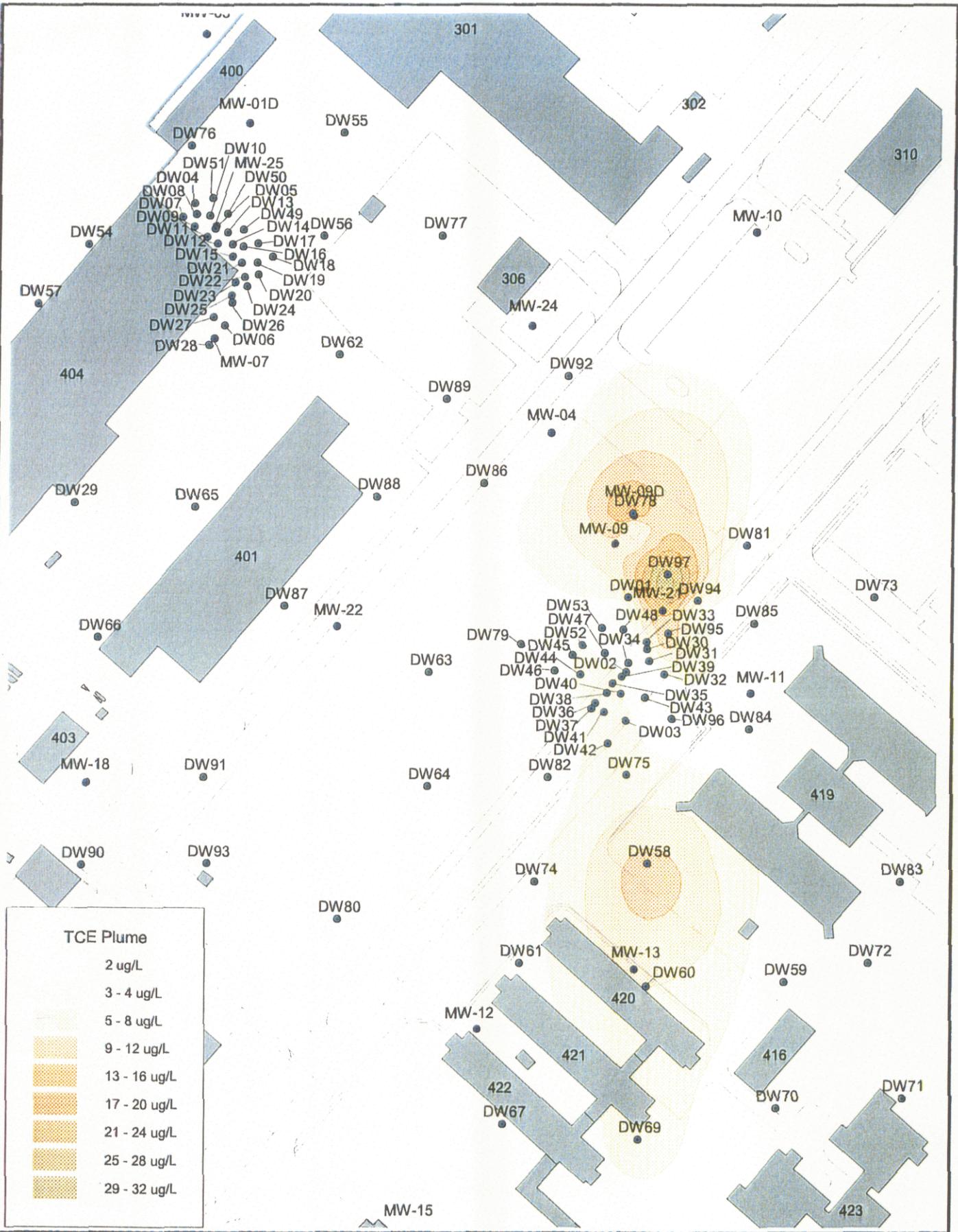


Figure 4-2  
TCE in Groundwater - SWMU 2C  
NAS Oceana, Virginia Beach, Virginia

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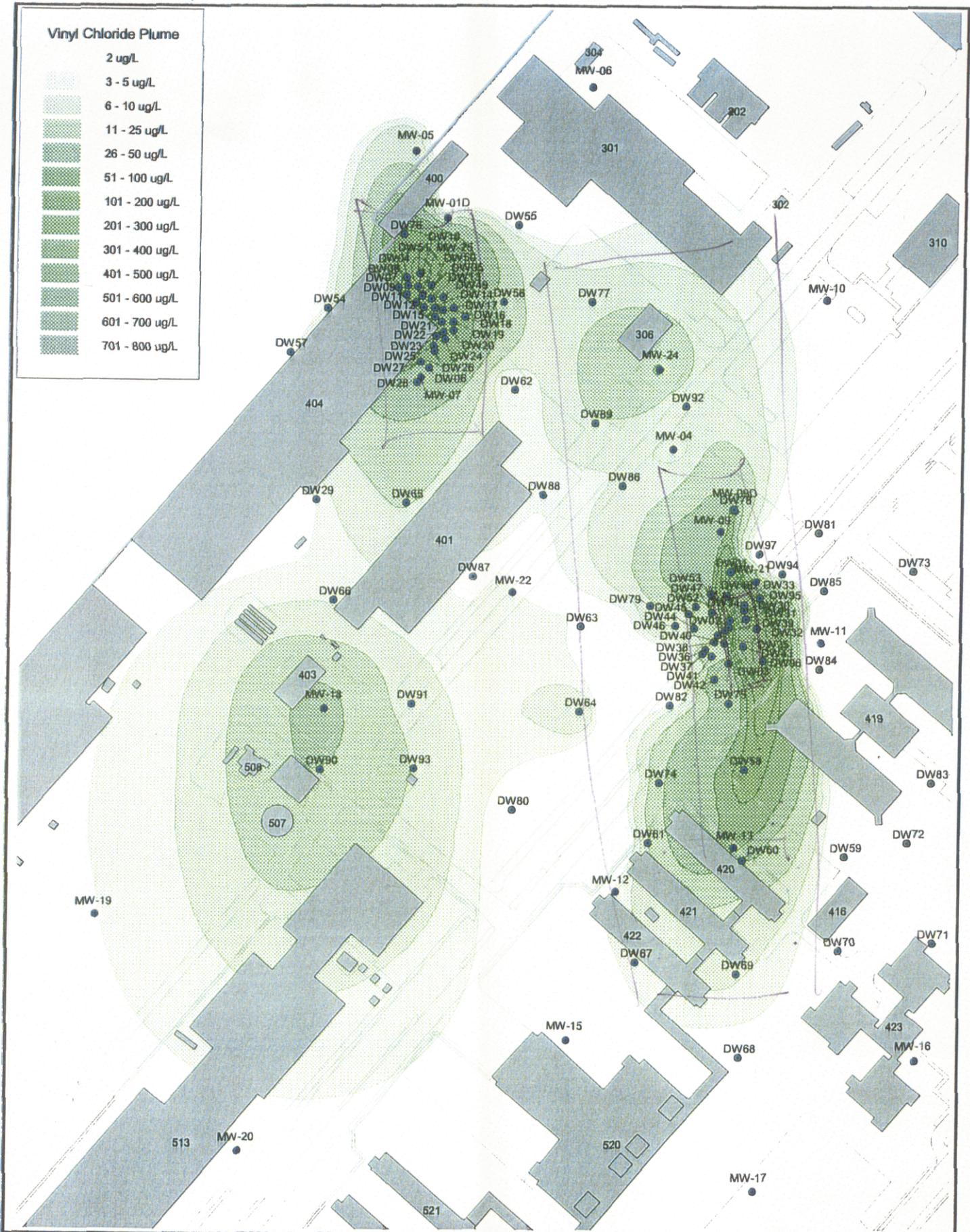


Figure 4-4  
Vinyl Chloride in Groundwater - SWMU 2C  
NAS Oceana, Virginia Beach, Virginia

the northern area the plume seems to originate near the northeastern wall of building 404. In the southern area the plume seems to originate near MW9 and MW9D and it extends southerly in the direction of groundwater flow, similarly to the TCE plume. In addition, a third area of vinyl chloride contamination exists around MW18. The distribution of vinyl chloride is much greater than its parent products TCE and *cis*-1,2-DCE, indicating that significant biodegradation has taken place and vinyl chloride seems to be accumulating in the groundwater. The factors governing natural attenuation are documented in the next section.

## 5.0 Vertical Profiling

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During August 1 through August 2, 2000, subsequent to the DPT sampling at SWMU 2C, COLUMBIA Technologies conducted a demonstration of Membrane Interface Probe (MIP) and Electrical Conductivity (EC) technology. The purpose of the test was to evaluate the performance of the MIP/EC technology at a site where concentrations of chlorinated solvent contamination had been previously delineated. The area of interest for this test was a hydraulic gradient-parallel transect of a dissolved chlorinated solvent plume consisting of TCE, 1,2-DCE, and vinyl chloride in the vicinity of MW25.

The objectives of the MIP/EC test were to:

1. Determine the degree of correlation between the contaminants identified by a MIP system equipped with a Flame Ionization Detector (FID), Photoionization Detector (PID) and Electron Capture Detector (ECD) with known contaminant concentrations determined by a recent (February, 2000) direct push sampling and on-site analyses event.
2. Determine relative minimum detection levels of the MIP system to various chlorinated contaminant compounds.
3. Determine the degree of vertical resolution that can be obtained for chemical contamination and electrical conductivity measurements using the MIP/EC system.
4. Verify there is no evidence of smearing of contaminants from one zone to another while using the MIP/EC system.
5. Determine to what degree contaminant compounds can be identified by using multiple detectors with the MIP/EC system.
6. Delineate the boundaries of the known contaminant plume.

### 5.1 Equipment Description

The MIP/SC probe is 1.5-inches (3.8 cm) in diameter and approximately 12-inches (30 cm) in length. The probe is driven into the ground at the rate of one foot per minute using a Geoprobe or similar direct push rig.

The soil conductivity portion of the tool utilizes a dipole measurement arrangement. An alternating electrical current is passed from the center, isolated pin of the SC probe to the probe body. The voltage response of the soil to the imposed current is measured across the same two points. The probe is reasonably accurate for measurement of soil conductivities in the range of 5 to 400 mS/m. In general, at a given location, lower conductivities will indicate sands while higher conductivities are indicative of silts and clays.

The MIP portion of the probe was developed and patented by Geoprobe Systems, Inc. The operating principle is based on heating the soil and/or water around a polymer membrane allowing volatile organic compounds (VOCs) to partition (absorb) into the polymer

membrane. Once VOCs are sorbed into the membrane, molecules will move by diffusion across the membrane to regions where their concentrations are lowest. Because the membrane is heated (80 to 125 degrees centigrade operating temperature) and the membrane is thin, this movement across the membrane is very rapid. After diffusing across the membrane, the VOCs partition into the carrier gas which sweeps the back side of the membrane. It takes about 35 seconds for the carrier gas stream to travel through about 100 feet of inert tubing and reach the installed detectors.

Columbia Technologies utilized a combination of three detectors: FID, PID, and ECD mounted on a laboratory grade gas chromatograph (Shimadzu 14A). The output signal from the detectors was then captured by a MIP data logging system installed on a laptop computer. Data is displayed continuously in real time during each push of the probe. In addition, the data logs can be printed for display and analysis following the data logging run or exported to common spreadsheet software.

## 5.2 Test Methods, Results, and Observations

Testing was conducted at five locations in a line approximately 150 feet in length along the groundwater gradient in SWMU 2C. The vertical profiling locations are co-located with previous direct push groundwater sample locations where chlorinated hydrocarbon concentrations were already determined. The locations are DW01, DW33, DW30, DW31, and DW43. DW30 was the groundwater sample location with the highest detection of vinyl chloride. Test locations are depicted on Figure 5-1. Multiple probes were conducted in each test location to evaluate the response of the different detectors. Logged results of response from the electrical conductivity detector, ECD detector, FID detector, and the suite of detectors at test location DW30 are presented as Figures 5-2 through 5-5, respectively.

The electrical conductivity logs consistently identified a region of lower permeability within 6 feet bgs, followed by a region of higher permeability down to 20 feet bgs, and then a mixture of high/low permeability between 20 and 22 feet bgs (Figure 5-2). These lithologic data are confirmed by monitoring well logs which indicate that the Columbia Aquifer, composed of fine- to medium-grained sand with minor silt is located at depths of approximately 6 to 20 feet bgs. The aquifer is semi-confined between two silt and clay units, one at the ground surface extending to approximately 6 feet bgs, and the other at a depth of approximately 20 feet bgs and extending to depths greater than 30 feet bgs.

An increasing response was noted on the ECD detector from 10 to 20 feet bgs and an abrupt signal response is evident from the uppermost zone of the silt-clay confining unit between 20 and 23 feet bgs (Figure 5-3).

A significant response was noted on the FID detector just beneath (6 to 10-feet bgs) the region of lower permeability, indicating a possible accumulation of methane at the top of the aquifer. These data are supported by the methane concentrations detected in groundwater that were observed to be lower at sample depths of 15 feet bgs when compared to concentrations detected at sample depths of 9 feet bgs.

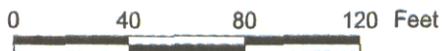
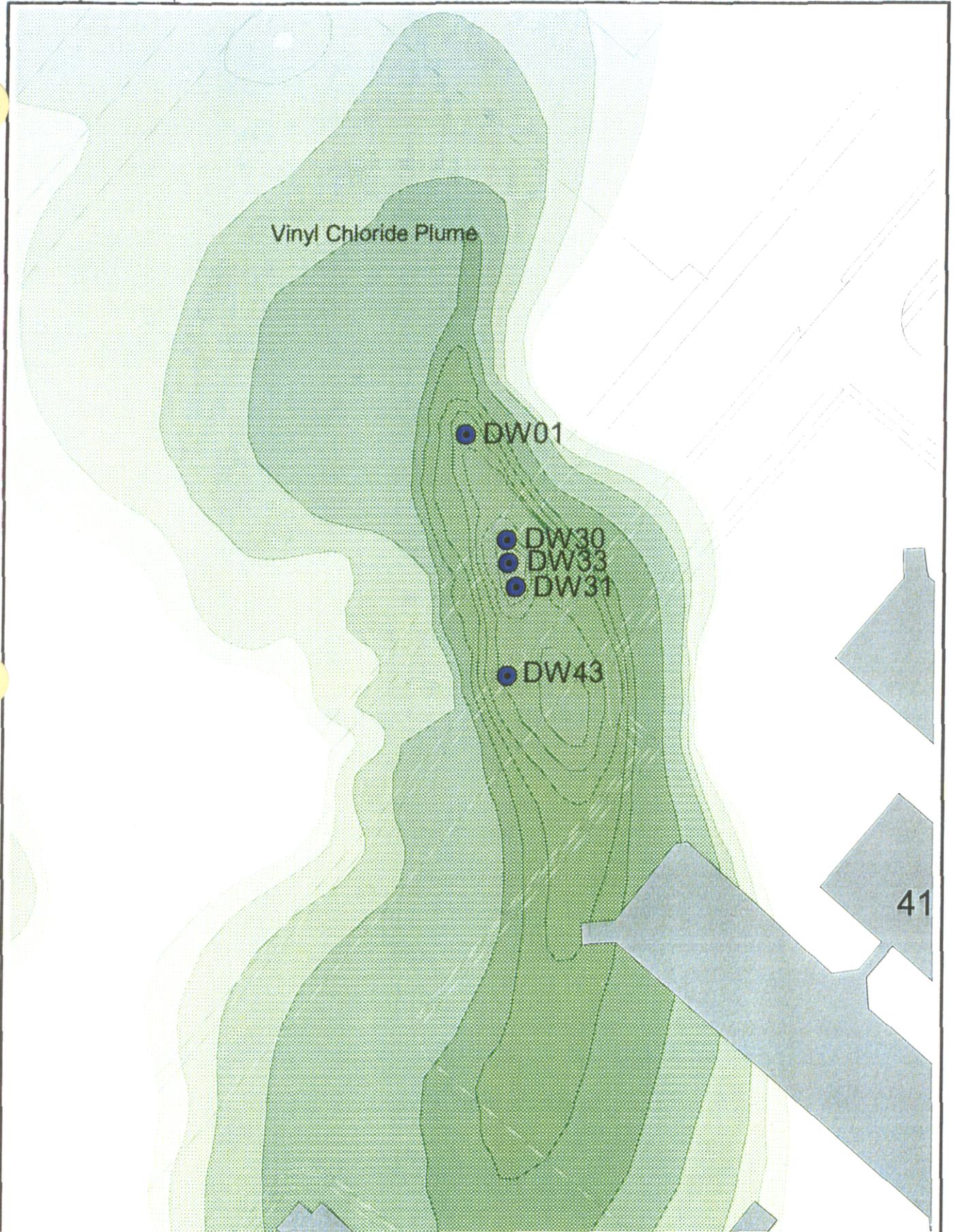


Figure 5-1  
Vertical Profiling Locations - SWMU 2C  
NAS Oceana, Virginia Beach, Virginia

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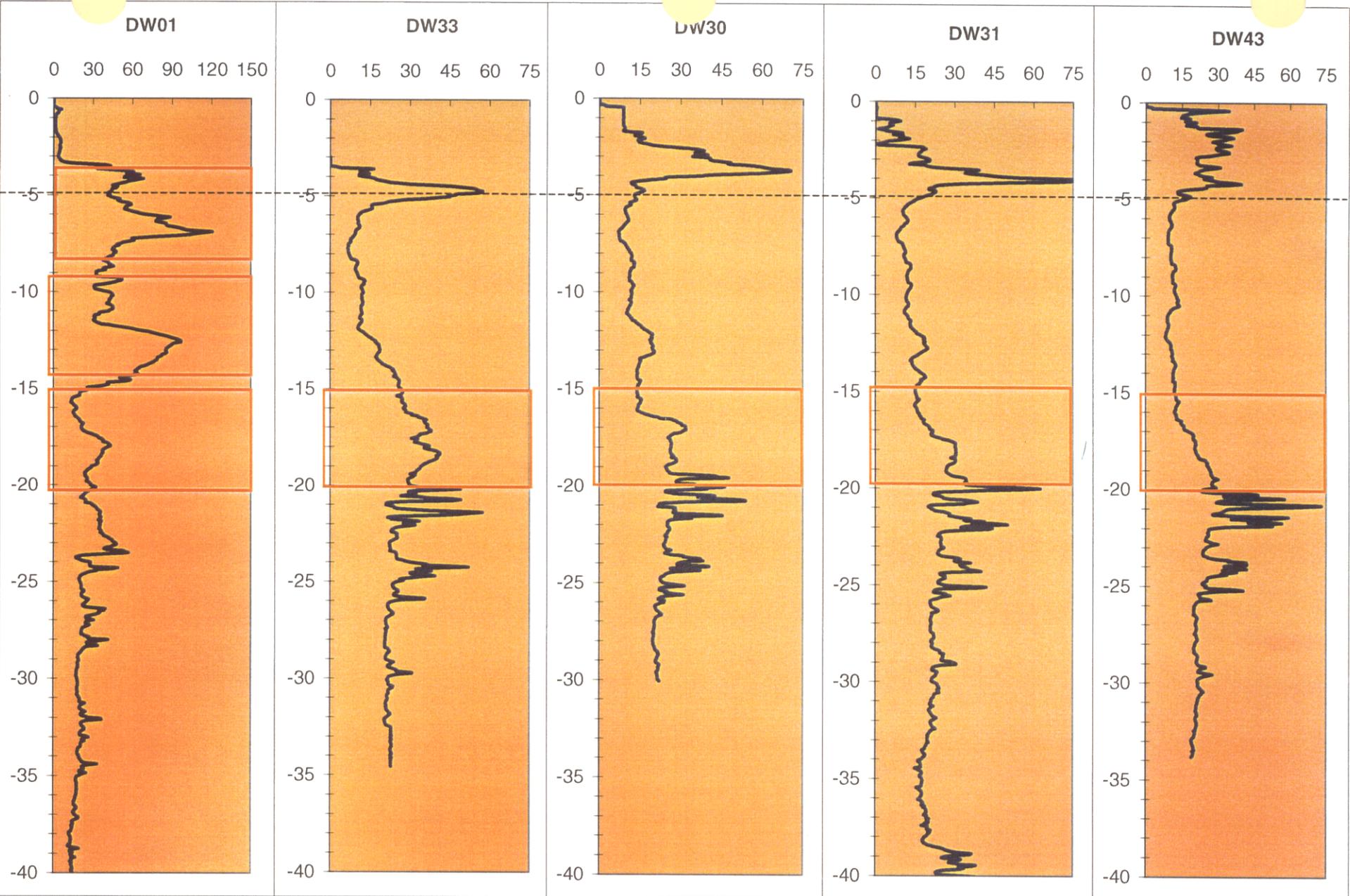


Figure 5-2: Electrical Conductivity Results from vertical profiles in August 2000.

 Sampling interval in March 2000  
 Ground water level

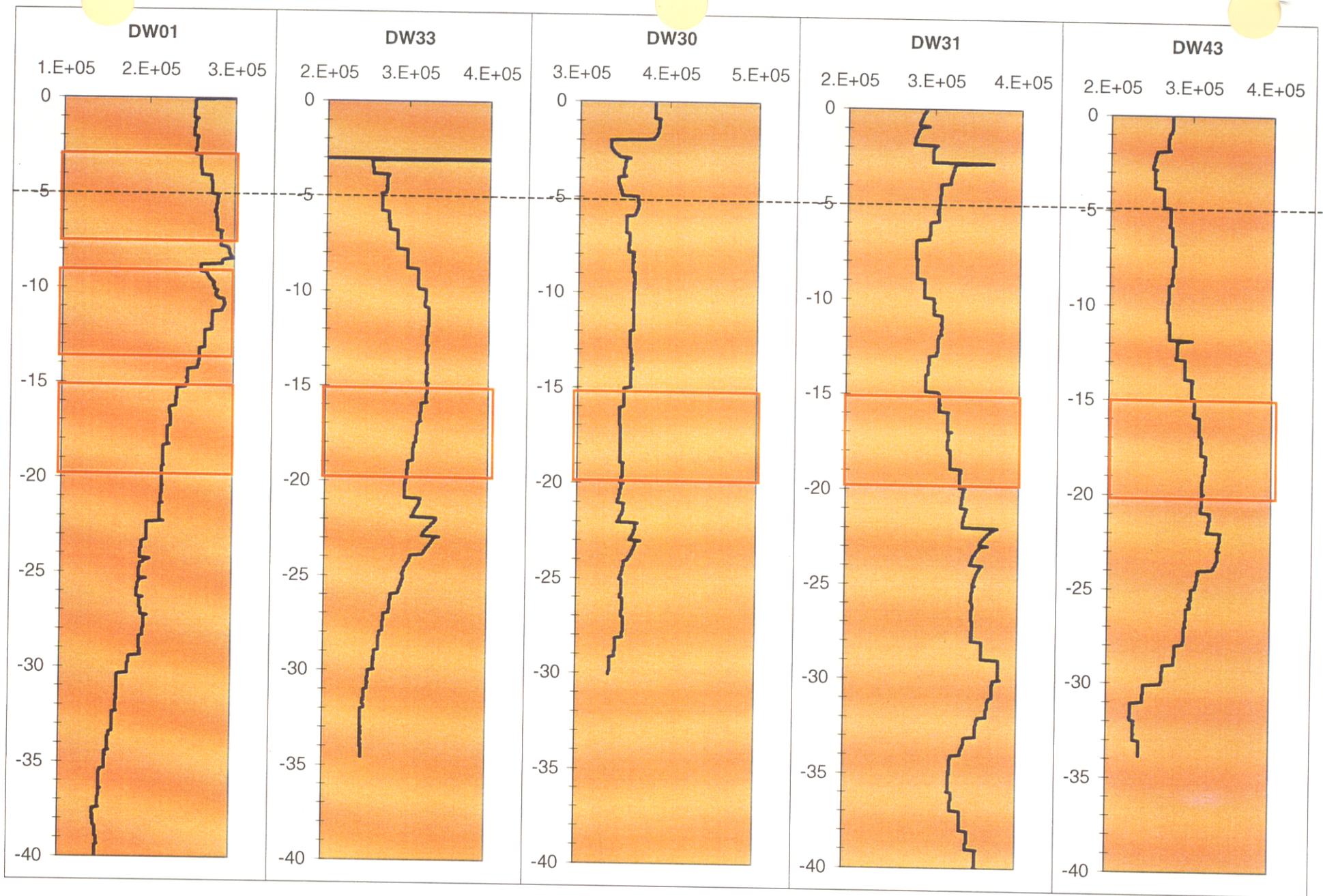
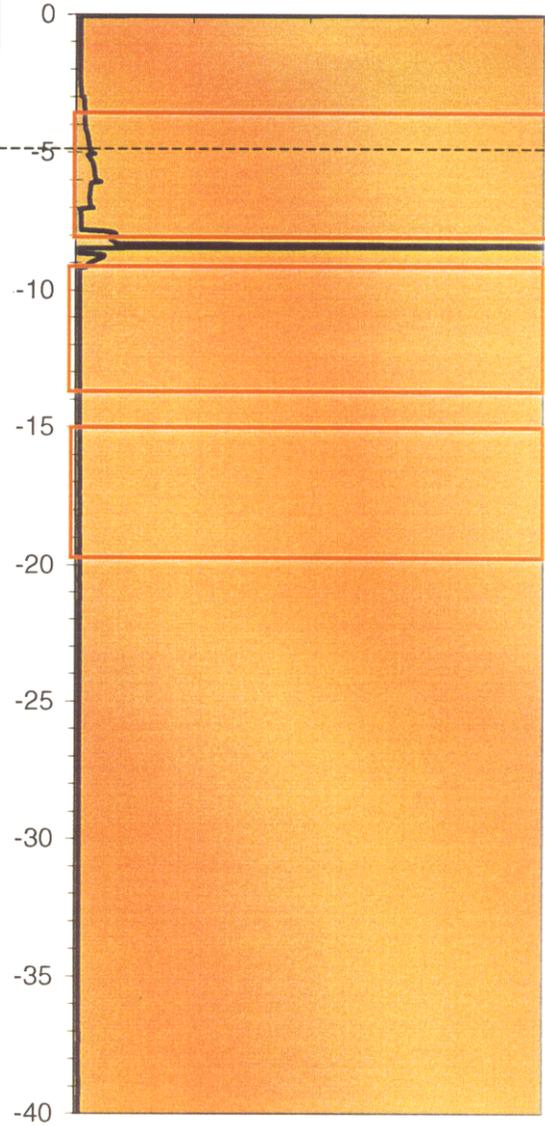


Figure 5-3: ECD Detector Results from vertical profiles in August 2000.

 Sampling interval in March 2000  
 Ground water level

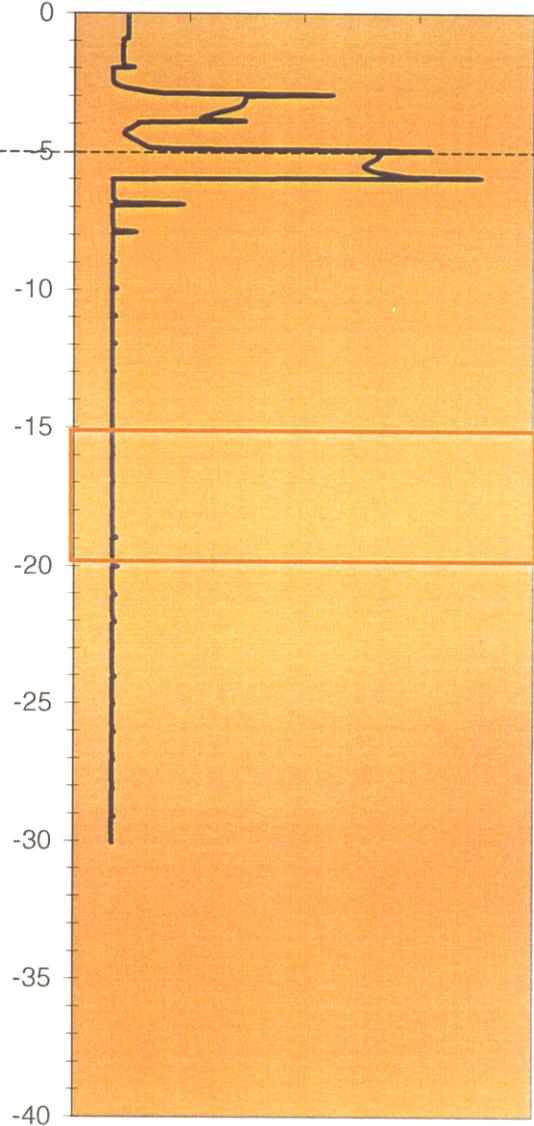
DW01

0.E+00 3.E+06 5.E+06 8.E+06 1.E+07



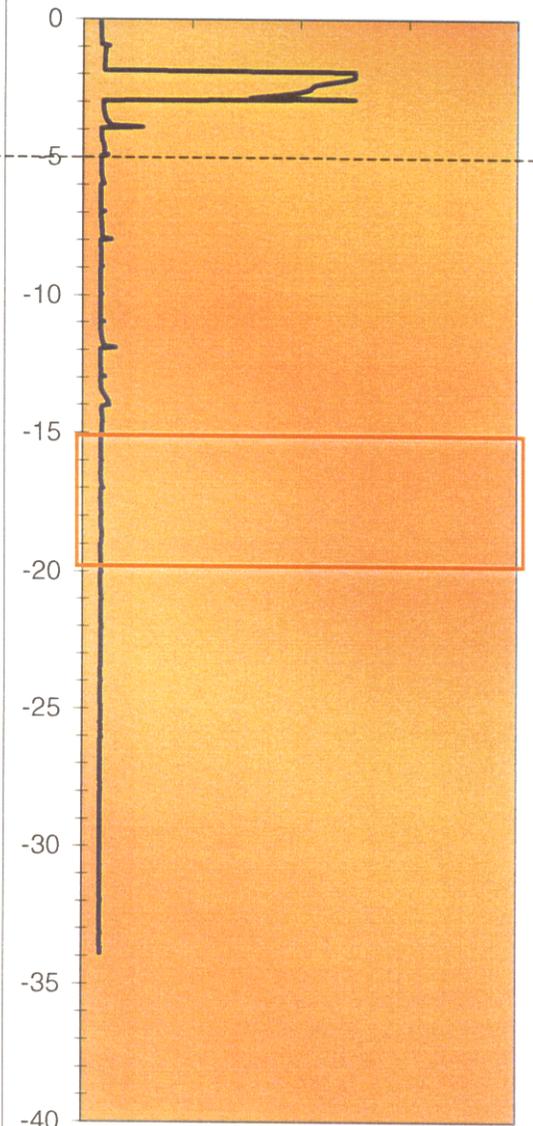
DW30

0.E+00 3.E+05 5.E+05 8.E+05 1.E+06



DW43

0.E+00 5.E+05 1.E+06 2.E+06 2.E+06



 Sampling interval in March 2000  
 Ground water level

Figure 5-4: FID Detector Results from vertical profiles in August 2000.

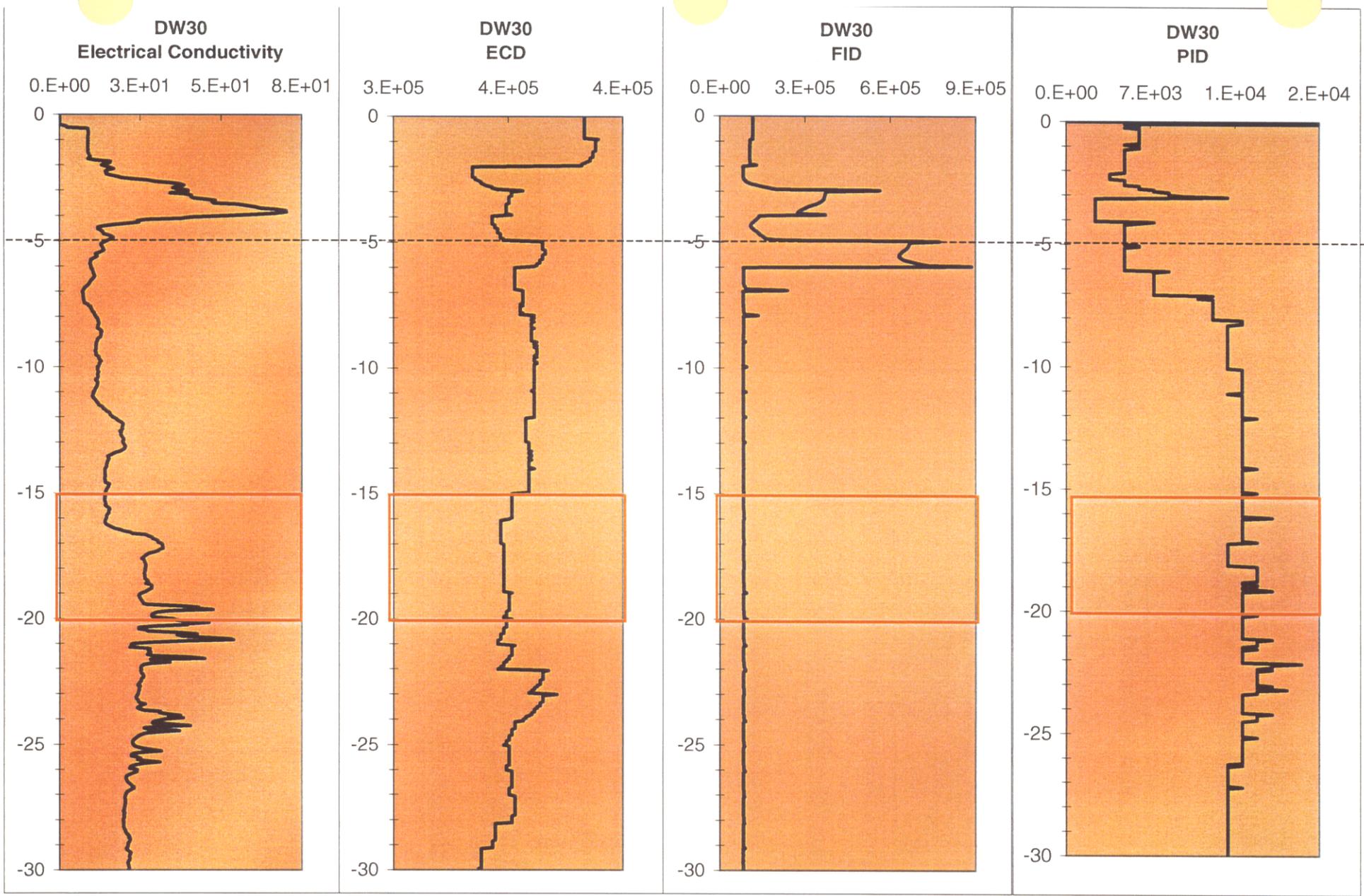


Figure 5-5: Vertical profile results from sample location DW30 in August 2000.

- Sampling interval in March 2000
- Ground water level

Little or no response was noted on the PID detector in many of the boring locations. However, the PID response at location DW30 shows a correlation with the ECD detector which indicates apparent elevated chlorinated concentrations between 21 and 24 feet bgs (Figure 5-4).

There was no apparent smearing of contaminant from one vertical zone to another based on the MIP/EC detector response. The MIP/EC system responded well in both unsaturated and saturated soil conditions.

The maximum detector output in response to chlorinated hydrocarbon contaminant concentrations occurred within the uppermost interval of the silt and clay confining unit at depths of 20 to 22 feet bgs. This depth interval is below where the previous direct push ground water sampling was conducted (i.e., at depths of 9 and 15 feet bgs). This depth interval is below where traditional sampling would most likely be attempted in the absence of the information provided by the MIP/EC, and this depth interval would present difficulties in obtaining a groundwater sample because of the low-permeability conditions. Because the maximum contaminant concentration as detected by the MIP/EC system was at a depth approximately 6 feet deeper than determined by direct push sampling and close support laboratory analyses in February 2000, it is possible that the maximum contaminant concentrations derived from the groundwater sampling results may be biased low.

The relatively low response of the ECD relative to test spikes indicates that the MIP technology is best suited for use in areas with elevated TCE. TCE has significantly more chlorine atoms than does vinyl chloride, the most prevalent chlorinated hydrocarbon compound found in groundwater at SWMU 2C. Higher chlorine atom compositions yield higher responses in the ECD.

## 6.0 Natural Attenuation

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The potential for the natural attenuation of chlorinated hydrocarbons detected in the groundwater at SWMU 2C is documented below. The primary chlorinated hydrocarbon contaminants of concern are TCE and its daughter products, *cis*-1,2- DCE and vinyl chloride. The occurrence and degradation of these compounds are addressed in this section. TCE is known to have been used as a solvent at the facility. However, most, if not all of the TCE detected is attributed to direct release into the environment and not as a result of degradation from its parent PCE. TCE daughter products *cis*-1,2-DCE and vinyl chloride were not known to be released into the environment and their presence is considered to be due to the biodegradation of TCE. First, general principles of chlorinated hydrocarbon biodegradation are documented. Then, site-specific evidence which supports the biodegradation processes is presented.

### 6.1 Biodegradation of Chlorinated Hydrocarbons

The biodegradation process uses indigenous soil organisms to degrade contaminant to innocuous byproducts such as carbon dioxide and water. Not all contaminant are biodegradable, and chlorinated solvents are only completely degraded under special conditions. If these conditions are not met, or if one of the necessary requirements are limiting, the contaminant will not be completely degraded.

In the soil matrix organisms exist in two states, dormant and active. In order to degrade contaminants the organisms need to be in the active state. For this to occur, there are four requirements; nutrients, moisture, an electron donor, and a terminal electron acceptor. Moisture and nutrients are generally readily available in the subsurface. Therefore, the processes of electron donation or a terminal electron acceptance are generally the limiting factor in biodegradation.

Three processes govern the biodegradation of chlorinated hydrocarbons. They are reductive dechlorination/dehalogenation, oxidation, and cometabolism. In general, a chlorinated hydrocarbon contaminant must first be dechlorinated before degradation can occur. This process is called reductive dechlorination, where the contaminant acts as the terminal electron acceptor and hydrogen is the electron donor (Wiedemeier *et al*, 1999). The processes enabling the reduction and degradation of TCE, and its daughter products to carbon dioxide, the redox conditions necessary, and the relative speed of the reactions are delineated in Figure 6-1. The availability of oxygen is indicative of aerobic conditions, otherwise conditions are anaerobic.

Reductive dechlorination is the process where chlorine atoms are replaced by hydrogen atoms. This only occurs in anaerobic conditions, and as each chlorine atom is removed, it becomes increasingly difficult to remove the next one, this is because TCE is more electronegative than *cis*-1,2-DCE (because it has more Cl<sup>-</sup> atoms attached) and thus the process of reducing TCE to ethene slows down with each removal of a chlorine atom. Under anaerobic conditions, complete degradation of chlorinated compounds can only



occur after all the chlorine atoms have been removed. Frequently only the first, or the first and second chlorine atoms are removed, resulting in the accumulation of daughter products, *cis*-1,2-DCE and vinyl chloride. The accumulation of vinyl chloride is of great concern to regulators as it is a known human carcinogen, and is highly toxic at low concentrations. Under circumstances of accumulating vinyl chloride enhancement becomes necessary to drive reductive dechlorination to completion.

Reductive dehalogenation, otherwise known as halorespiration, is performed by a group of organisms known as halorespirators. These organisms utilize hydrogen as the electron donor, which is frequently the limiting factor, and the chlorinated compound as the terminal electron acceptor. Halorespirators are the only organisms which conduct reductive dehalogenation, but they are not the only organisms which utilize hydrogen. Halorespirators are most competitive for hydrogen when the redox conditions are between -150 and -320 mV, which are sulfate reducing and methanogenic conditions.

The following trends occur in environments undergoing reductive dehalogenation and biodegradation and can be monitored to determine if natural attenuation is occurring:

- Reduction in TCE concentrations
- Increase in *cis*-1,2-DCE concentrations
- Increase in vinyl chloride concentrations
- Increase in ethene and ethane concentrations
- Elevated chloride concentrations
- Methane production
- Low redox conditions
- Production of iron (II)

Oxidation is the process where the contaminant is used as a carbon source and is broken down directly into carbon dioxide and water. TCE is not degradable via this process, there is limited evidence that *cis*-1,2-DCE is degradable, but vinyl chloride is rapidly degraded in circumstances where oxygen is available as the terminal electron acceptor.

Cometabolism is an aerobic process where a carbon source other than the contaminant is degraded, and the chlorinated solvent is fortuitously degraded. This occurs because cells are 'leaky' meaning that during the growth process some cellular components and products are released into the environment. For example, during the degradation of methane an enzyme called MMO is produced. This enzyme adds an oxygen molecule to the methane. As the cell grows and divides, this enzyme is released into the environment, and will add an oxygen molecule to TCE, making it more amenable to degradation by another organisms. In the environment, cometabolism will only occur when there is oxygen and another carbon source, such as BTEX, methane, etc. available. When either the oxygen or the carbon source are depleted, cometabolism will cease (usually oxygen is depleted first). In engineered conditions, cometabolism can be achieved by the addition of oxygen and a carbon source such as methane, ethane, propane, butane, toluene, or phenol. The addition of oxygen and ammonium ( $\text{NH}_4^+$ ) has also been documented to support this process (Wiedemeier *et al*, 1999).

In summary, there are three sets of conditions able to achieve the degradation of TCE to carbon dioxide:

- Anaerobic conditions where the requirements for reductive dehalogenation are met followed by anaerobic degradation of vinyl chloride and ethene. These conditions can sometimes be met naturally, otherwise they need to be engineered.
- Anaerobic conditions where the requirements for reductive dehalogenation are met, followed by aerobic conditions. This sequence of conditions is rarely achieved naturally and need to be engineered by enhancement.
- Aerobic degradation via cometabolism, which requires the addition of oxygen and a carbon source such as methane. These conditions will only occur naturally for a short period of time and otherwise need to be engineered.

In this section of the report, TCE and its daughter products are evaluated for reductive dehalogenation and biodegradation according to the parameters outlined above.

## 6.2 Evaluation of Natural Attenuation

To demonstrate natural attenuation it is necessary to document at least two of the following three lines of evidence (NRC, 1994; ASTM, 1998):

1. Historical data showing plume stabilization and/or loss of contaminant over time.
2. Chemical and geochemical analytical data, including:
  - Depletion of terminal electron acceptors and donors.
  - Increasing metabolic by-product concentrations.
  - Decreasing parent compound concentrations.
  - Increasing daughter product concentrations.
3. Microbiological data that support the occurrence of degradation and gives estimates of biodegradation rates.

The first line of evidence should show that the plume is stabilized or is shrinking in size. This line of evidence does not prove that the contaminants are being destroyed. Reduction in contaminant concentration could be the result of advection, dispersion, dilution from recharge, sorption, and volatilization. However, this line of evidence is critical for determining if any exposure pathways exist for current or potential future receptors. Providing historical groundwater data at appropriate monitoring or sampling points that show a trend of decreasing contaminant mass and/or concentration over time is sufficient to support this first line of evidence.

The second line of evidence relies on chemical and physical data to show that contaminant mass is being destroyed, not just being diluted or sorbed to the aquifer matrix. This is accomplished by measuring the changes in groundwater chemistry that occur during biodegradation. Each type of terminal electron acceptor causes a unique change in the groundwater's chemistry.

- During aerobic respiration, oxygen is reduced to water, and dissolved oxygen concentrations decrease.

- In anaerobic systems where nitrate is the electron acceptor, the nitrate is reduced to  $\text{NO}_2^-$ ,  $\text{N}_2\text{O}$ ,  $\text{NO}$ ,  $\text{NH}_4^+$ , or  $\text{N}_2$ , and nitrate concentrations decrease.
- In anaerobic systems where iron(III) is the electron acceptor, iron(III) is reduced to iron(II), and iron(II) concentrations increase.
- In anaerobic systems where sulfate is the electron acceptor, sulfate is reduced to  $\text{H}_2\text{S}$ , and sulfate concentrations decrease.
- In anaerobic systems where carbon dioxide is used as an electron acceptor, carbon dioxide is reduced by methanogenic bacteria, and methane is produced.

Thus an active zone of biodegradation will have depleted dissolved oxygen, nitrate, and sulfate and/or elevated iron(II) and methane concentrations. This evidence can be used to show that electron acceptor/donor concentrations in groundwater are sufficient to facilitate degradation of dissolved contaminants.

The third line of evidence is directed toward proving that the soil has the microbial capacity to degrade the contaminant. This is most commonly done by performing microcosm studies. This is the least utilized line of evidence because while it indicates that the soil has the potential to degrade the contaminant, it does not show that degradation is actually occurring. This line of evidence is not considered in this evaluation of natural attenuation.

## 6.3 Plume Stabilization, Shrinkage, or Contaminant Reduction Related to Biodegradation

In this section, site-specific biodegradation processes for detected chlorinated hydrocarbon contaminants are examined as they relate to biodegradation trends and lines of evidence for natural attenuation.

### 6.3.1 Reduction in TCE Concentrations

The first line of evidence should show that the TCE plume is stabilized or is shrinking in size due to advection, dispersion, dilution from recharge, sorption, and volatilization. In the northern study area around MW25, TCE was not detected during the RFI and CMS studies. Although MW25 did not exist until 1999, this area was monitored historically by sampling MW01 and direct push sampling of location GP13. Either TCE was not ever present or it has been completely dechlorinated. Since the daughter products *cis*-1,2-DCE and vinyl chloride are present and these chemicals are not generally utilized in solvent form and TCE was historically commonly used as a solvent on the flight line, one could assume that TCE was disposed in the area and has subsequently completely biodegraded into *cis*-1,2-DCE and vinyl chloride.

In the southern study area, there has been a reduction in the concentration of TCE in MW09. The concentration recorded in August 1990 was 63 ug/L. In January 1993 the concentration was 29 ug/L and in February 2000 the concentration was similar at 33 ug/L. Further south and hydraulically downgradient, the area near MW21 was previously monitored by direct push sampling at location GP03. In February 1994, the concentration was 3 ug/L. In February 2000, the concentration in MW21 was 6.5 ug/L.

The second line of evidence relies on chemical and physical data to show that contaminant mass is being destroyed. Additional groundwater sample data are required in order to assess future reductions and the natural attenuation process. However, the detection in groundwater of daughter products associated with the degradation of TCE is direct evidence that some contaminant mass is being destroyed, assuming that daughter products of TCE were not released.

TCE dechlorinates in an anaerobic environment but will biodegrade through cometabolism in an aerobic environment. The distribution of dissolved oxygen relative to the concentrations of TCE detected in groundwater is depicted in Figure 6-2. In the area of MW21, TCE is not detected but daughter products are present. Dissolved oxygen is now depleted compared to background conditions, indicating that aerobic conditions could have existed in this area at one time. TCE might have degraded under aerobic conditions, co-metabolically with petroleum hydrocarbons resulting in the complete degradation of TCE, the production of daughter products, and the depletion of dissolved oxygen. Some residual BTEX is present in this area.

In the area of MW25, aerobic conditions might have existed where the TCE is detected, as indicated by a decrease in dissolved oxygen in areas of elevated TCE concentration relative to background locations. There is no evidence of co-metabolic degradation. The current reducing environment is favorable for continued degradation of TCE.

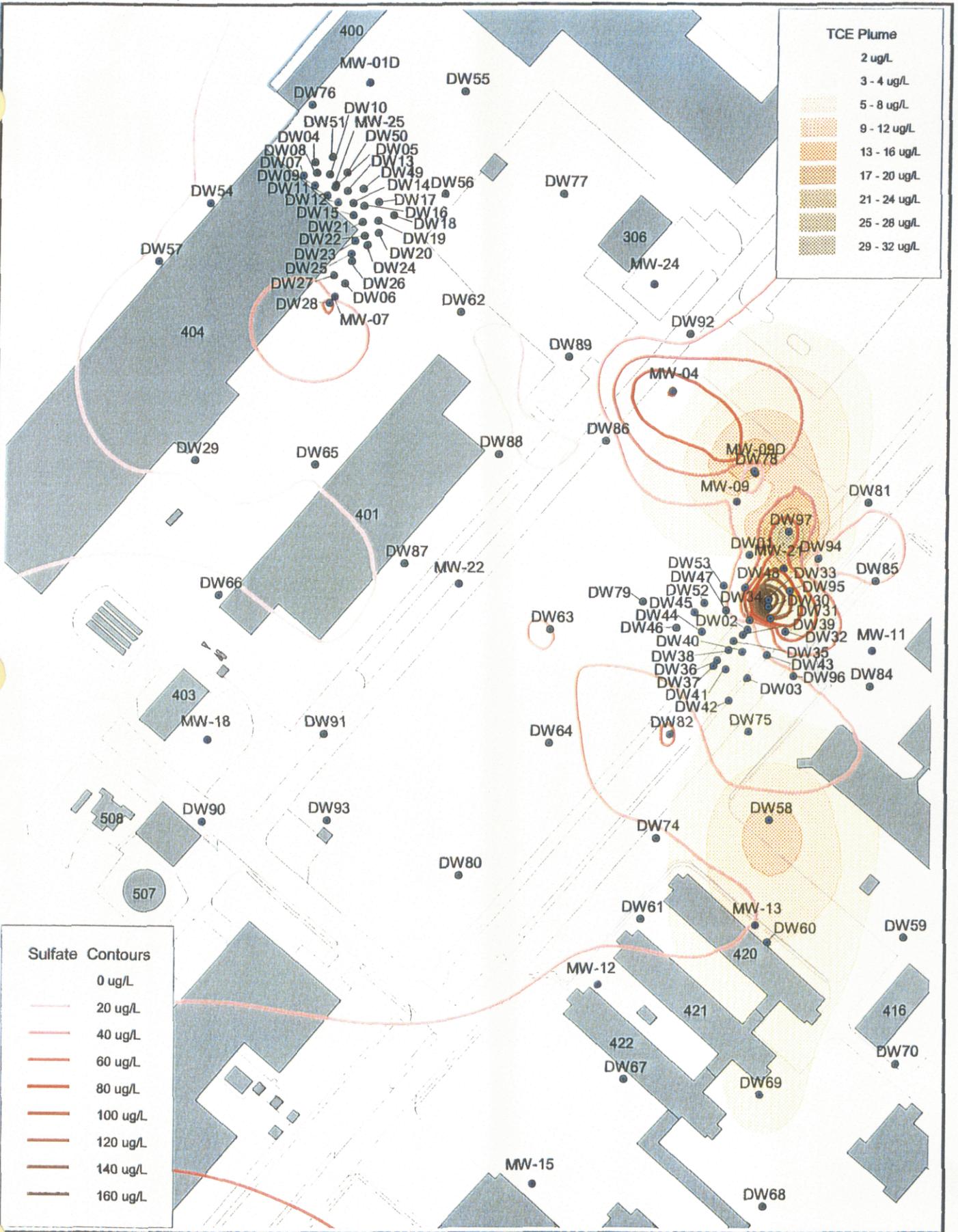
In anaerobic systems where nitrate is the electron acceptor, the nitrate is reduced. The distribution of nitrate relative to the concentrations of TCE detected in groundwater is inconclusive since nitrate levels are low across the entire site. In anaerobic systems where sulfate is the electron acceptor, the sulfate is reduced. The distribution of sulfate relative to the concentrations of TCE detected in groundwater is depicted in Figure 6-3. This figure shows that anaerobic degradation of TCE through sulfate reduction might be occurring. Increases in sulfate concentrations in the area of elevated TCE concentration are observed relative to areas outside of the plume.

In anaerobic systems where carbon dioxide is used as an electron acceptor, carbon dioxide is reduced by methanogenic bacteria, and methane is produced. Concentrations of methane detected in the DPT and monitoring wells relative to the concentrations of TCE detected in groundwater are depicted in Figure 6-4. Anaerobic degradation of TCE is inconclusive. Although methane is elevated in the northern source area, it is also elevated in background locations around the known plume areas. Also, a significant decrease in concentration is evident where sample depths were increased from 9 to 15 feet bgs. This variation creates significant bias in the data. PID readings indicate possible accumulations of methane near the ground surface in comparison to depths when compared to the PID results. This trend is reflected in the groundwater analytical results.

### 6.3.2 Increase in *cis*-1,2-DCE Concentrations

The presence of *cis*-1,2-DCE in TCE-contaminated groundwater is generally indicative of TCE biodegradation. An increase in *cis*-1,2-DCE concentrations corresponding with a decrease in TCE concentrations would serve as an indicator that reductive dechlorination is occurring and TCE is biodegrading into *cis*-1,2-DCE. However, the decrease in *cis*-1,2-DCE





0 90 180 270 Feet

Figure 6-3  
Sulfate in Groundwater Over TCE  
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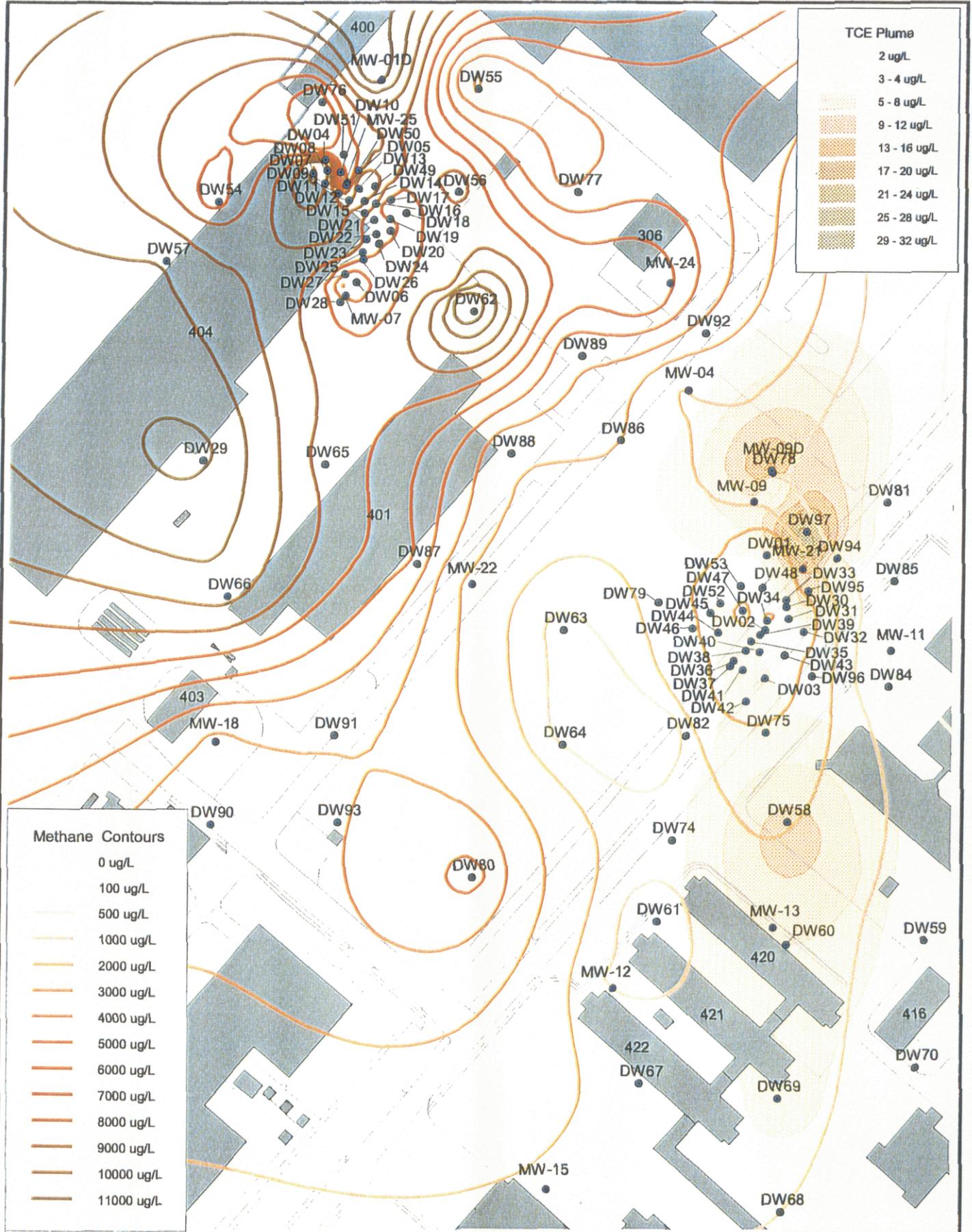


Figure 6-4  
Methane in Groundwater Over TCE  
NAS Oceana, Virginia Beach, Virginia

with a concurrent increase in vinyl chloride concentrations could indicate that there was ample reduction of TCE to *cis*-1,2-DCE and that the degradation process continued as *cis*-1,2-DCE decreased in concentration and vinyl chloride increased.

In the northern study area around MW25 where TCE is not detected, *cis*-1,2-DCE was detected at a concentration of 240 ug/L in November 1992. In February 2000, the highest observed concentration was 214 ug/L. The presence of *cis*-1,2-DCE and the absence of TCE supports the reduction of TCE to *cis*-1,2-DCE. A decrease in *cis*-1,2-DCE could indicate that *cis*-1,2-DCE is degrading to vinyl chloride.

In the southern study area, MW09 had a concentration of 1600 ug/L in January of 1993. In February 2000, the concentration had decreased significantly to 56 ug/L. However, 100 feet hydraulically downgradient at DPT location DW01, *cis*-1,2-DCE was detected at 676 ug/L in February 2000. Elevated *cis*-1,2-DCE detections near MW09 have apparently migrated downgradient and are being also being reduced. Historic DPT sampling location GP03 had 21 ug/L of *cis*-1,2-DCE in November 1992. In February 2000, 35 ug/L of was detected in MW21, located nearby. These data are inconclusive but can be interpreted to demonstrate an increase in *cis*-1,2-DCE due to the reduction of TCE and a decrease in *cis*-1,2-DCE corresponding to an increase in vinyl chloride.

The biodegradation of *cis*-1,2-DCE can occur either aerobically or anaerobically. The aerobic process is faster. The presence of vinyl chloride in the aquifer supports the biodegradation of *cis*-1,2-DCE. The distribution of dissolved oxygen, and sulfate support the potential for the slower, anaerobic, biodegradation of *cis*-1,2-DCE into vinyl chloride.

### 6.3.3 Increase in Vinyl Chloride Concentrations

The presence of vinyl chloride in *cis*-1,2-DCE -contaminated groundwater is generally indicative of *cis*-1,2-DCE biodegradation. An increase in vinyl chloride concentrations corresponding with a decrease in *cis*-1,2-DCE concentrations would serve as an indicator that dechlorination is occurring and *cis*-1,2-DCE is biodegrading into vinyl chloride.

In the northern study area, in November 1992, 130 ug/L of vinyl chloride was detected in DPT sample location GP13, and in January 2000, 560 ug/L was detected in MW25 located in the same vicinity. In the southern study area, the concentration of vinyl chloride detected in MW09 was 340 ug/L, in January 1993. In February 2000, the concentration of vinyl chloride detected in MW09 was 56 ug/L, a significant decrease. However, 100 feet hydraulically downgradient, 24 ug/L of vinyl chloride was detected in November 1992 and in February 2000, the concentrations detected in DW30 and DW31 are 897 ug/L and 817 ug/L, respectively. Apparently, DCE is being dechlorinated, resulting in an increase in vinyl chloride at SWMU 2C.

Vinyl chloride degrades rapidly under aerobic conditions and slowly under anaerobic conditions. The presence of ethene in the aquifer is evidence of the biodegradation of vinyl chloride. The distribution of dissolved oxygen and sulfate support the potential for the slower anaerobic biodegradation of vinyl chloride into ethene.

### 6.3.4 Increase in Ethene Concentrations

Ethene is a daughter product that results from the dechlorination of vinyl chloride. The presence of elevated ethene relative to background locations is indicative of the biodegradation of vinyl chloride.

Figure 6-5 illustrates the distribution of ethene in groundwater relative to the vinyl chloride plume. This figure clearly demonstrates that vinyl chloride is biodegrading to ethene. Figure 6-6 shows the distribution of dissolved oxygen in the aquifer relative to the vinyl chloride plume. The dissolved oxygen is depleted within the plume indicating the depletion of oxygen and the anaerobic dechlorination of TCE, *cis*-1,2-DCE, and vinyl chloride. Vinyl chloride degrades to ethene slowly under anaerobic conditions compared to aerobic conditions. Therefore, vinyl chloride would be expected to accumulate when the rate of production exceeds the rate of natural attenuation. This is interpreted to be occurring in groundwater at SWMU 2C based on the observed significant vinyl chloride plume detected during the sampling event.

### 6.3.5 Elevated Chloride Concentrations

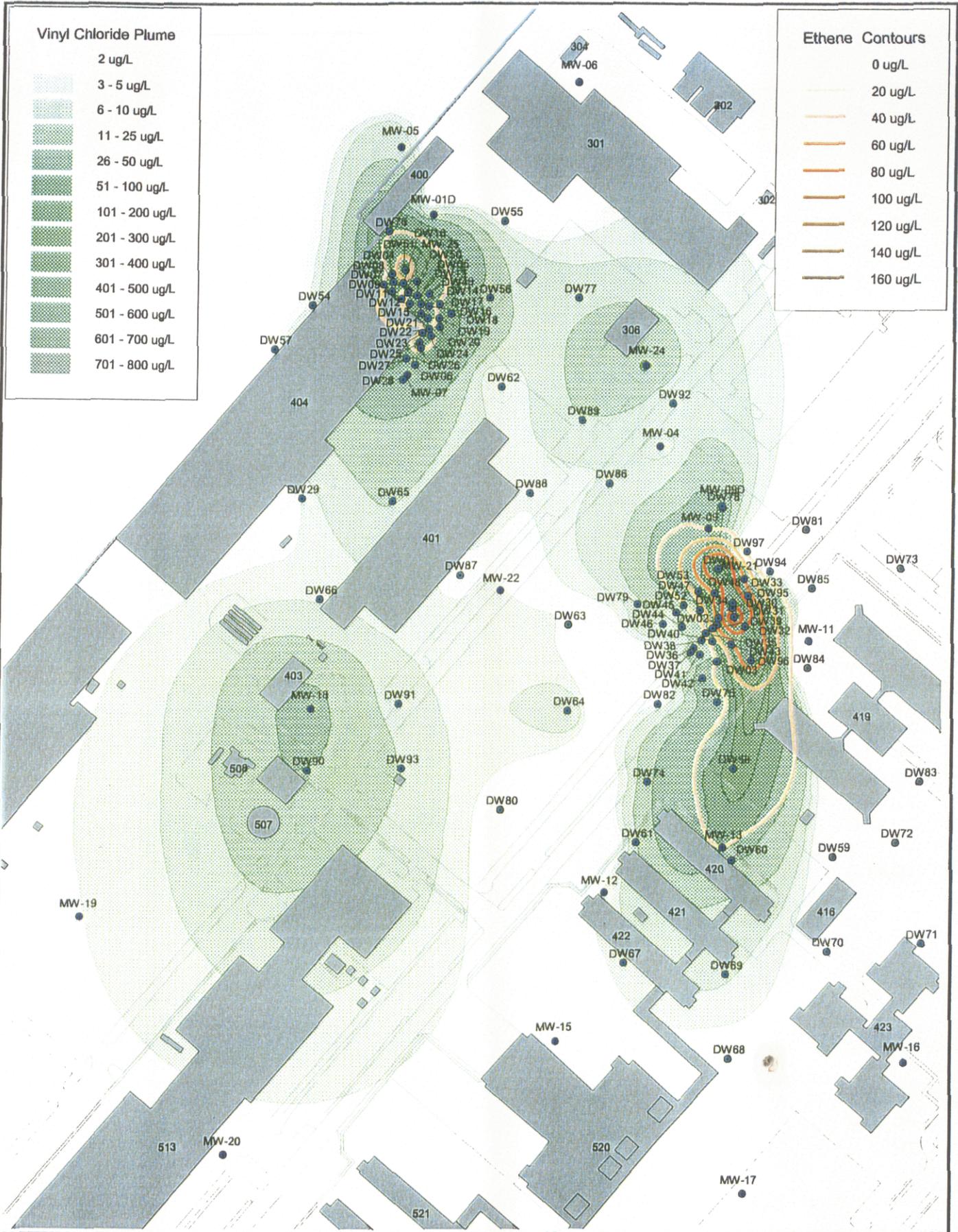
The presence of elevated chloride concentrations in chlorinated hydrocarbon-contaminated groundwater, with respect to background concentrations is generally indicative of chlorinated hydrocarbon biodegradation. As reductive dechlorination occurs, chlorine atoms are stripped from the chlorinated hydrocarbon. The distribution of chloride in groundwater is depicted in Figure 6-7. The area with the most elevated chloride concentrations in groundwater corresponds with areas of elevated TCE, *cis*-1,2-DCE, and vinyl chloride concentrations.

### 6.3.6 Summary of Natural Attenuation of Chlorinated Hydrocarbons

In summary, biodegradation of chlorinated hydrocarbons in groundwater through reductive dechlorination and cometabolism is likely to have occurred and in some cases, is continuing to occur. It appears that vinyl chloride is being further reduced to ethene. However, at this time vinyl chloride appears to be accumulating. Therefore, enhanced bioremediation is a viable consideration to augment the natural biodegradation process.

The first line of evidence for natural attenuation evaluated in this study should show that contaminant plumes are stabilized or are shrinking in size. TCE contaminant concentrations appear to be decreasing over time. The *cis*-1,2-DCE plume is interpreted to have increased at one time and is now on the decline due to reduction to vinyl chloride. However, a significant accumulation of vinyl chloride concentrations indicate that conditions might not be optimal for effective natural attenuation even though significant ethene production is observed.

The second line of evidence evaluated in this study relies on observable changes in groundwater chemistry that occur during biodegradation. TCE is known to have been released at the site. Daughter products that result from TCE degradation, namely *cis*-1,2-DCE, vinyl chloride, and ethene, are all detected in groundwater at the SWMU in locations that support their provenance from their parent product. In addition, sulfate reduction and chloride production, support the interpretation that anaerobic degradation of chlorinated



0 100 200 300 Feet

Figure 6-5  
Ethene over Vinyl Chloride - SWMU 2C  
NAS Oceana, Virginia Beach, Virginia

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hydrocarbons is occurring in groundwater. However, the accumulation of vinyl chloride indicates that the natural attenuation process might need to be augmented with enhanced biodegradation. Recommendations will be documented in the next section.

When another assessment of natural attenuation is completed at SWMU 2C, a more detailed analysis of chemistry changes, with supporting stoichiometry, calculated capacities for assimilation, and contaminant degradation modeling, should be conducted if monitored natural attenuation is to be evaluated as a remedial alternative for groundwater.

# 7.0 Enhanced Biodegradation

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In order to achieve complete degradation of the chlorinated hydrocarbon contaminants at SWMU 2C, active groundwater remediation in combination with attenuation enhancement is recommended. These are summarized below. A more complete assessment of remedial alternatives will be developed in the focused feasibility study for SWMU 2C.

## 7.1 Active Groundwater Remediation

Active groundwater remediation is a viable consideration for the remediation of elevated chlorinated hydrocarbon contamination at specific locations where the contaminant concentrations are the highest ("hot spots"). Methods that could be considered are NoVOCs® or similar technologies which aerate the groundwater to strip off the volatile contaminants and re-circulate the treated groundwater. Other "hot-spot" remedial technologies could also combine groundwater aeration or re-circulation with augmentation with compounds which enhance attenuation of chlorinated compounds. A discussion of these compounds is documented below.

## 7.2 Attenuation Enhancement

Three possible attenuation enhancement strategies could be applied:

1. The addition of hydrogen to continue the reductive dehalogenation process.
2. The addition of a carbon source or ammonium with oxygen to achieve cometabolism.
3. The addition of oxygen to create aerobic conditions and enhanced oxidation.

### 7.2.1 Addition of Hydrogen

Hydrogen is necessary for reductive dehalogenation to take place. The addition of hydrogen would facilitate the dehalogenation of TCE and *cis*-1,2-DCE. Direct injection of hydrogen either as a gas or a liquid is infeasible. However, the injection of a carbon source which produces hydrogen during degradation is practical. Some products which have been used are molasses, lactic acid and Hydrogen Release Compound (HRC®). HRC stimulates the multi-step process of creating an environment for optimum reductive dehalogenation, and then slowly releases lactic acid which releases hydrogen during the degradation process.

### 7.2.2 Addition of Oxygen

The addition of oxygen would be appropriate as a treatment for the site-wide vinyl chloride plume. Treatability tests will need to be conducted to determine if the *cis*-1,2-DCE is amenable to aerobic degradation. Addition of oxygen would be the most rapid method to treat the vinyl chloride plume. The oxygen is utilized as a terminal electron acceptor, and the contaminant is the electron donor. There are several methods of oxygen introduction including the addition of air with biosparging (similar to air sparging, but at low volumes

to promote degradation not volatilization), addition of compounds which release oxygen, such as Oxygen Release Compound® (ORC ®) or magnesium peroxide, and the addition of pure oxygen.

### **7.2.3 Addition of a Carbon Source**

The addition of a carbon source or ammonium in conjunction with oxygen would be a feasible remedy for the reduction of vinyl chloride in elevated areas, but might be impractical for the entire vinyl chloride plume.

## 8.0 Conclusions

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Groundwater at SWMU 2C contains concentrations of TCE, *cis*-1,2-DCE, and vinyl chloride at concentrations that exceed MCLs. Benzene is also detected at levels that exceed MCLs. Discrete-depth groundwater sampling at SWMU 2C indicated that the highest chlorinated compound detections in the Columbia aquifer were located at depths of approximately 9 feet bgs near MW21 in the northern part of the SWMU and at depths of approximately 15 feet bgs near MW25 in the southern part of the SWMU.

MIP/EC survey work confirmed that contaminant occurrence is controlled by lithology. The greatest response to the ECD was at a depth interval of 21 to 24 feet bgs, in the upper strata of the lower confining unit. However, the low permeability of this unit would inhibit effective groundwater sampling. The MIP/EC survey showed that the EC probe response correlates with logged lithology at the SWMU. The MIP response indicated muted responses of the ECD to chlorinated hydrocarbon contamination compared to spike samples due to the prevalence of vinyl chloride over TCE. Vinyl chloride had far fewer chlorine atoms. The PID detector indicated the potential accumulation of methane at the top of the Columbia Aquifer. This finding was further supported through groundwater sampling which showed higher methane concentrations within the aquifer at 9 feet bgs than at 15 feet bgs.

The natural attenuation assessment indicated that biodegradation of chlorinated hydrocarbons in groundwater through reductive dechlorination and cometabolism is likely to have occurred and in some cases, is continuing to occur. It appears that TCE is being reduced to *cis*-1,2-DCE, which is being further reduced to vinyl chloride, which is being further reduced to ethene. However, at this time, vinyl chloride appears to be accumulating. Therefore, enhanced bioremediation is a viable consideration to augment the natural biodegradation process.

The first line of evidence for natural attenuation indicates that TCE contaminant concentrations appear to be decreasing over time. The *cis*-1,2-DCE plume is interpreted to have increased at one time and is now on the decline due to reduction to vinyl chloride. However, a significant accumulation of vinyl chloride concentrations indicate that conditions might not be optimal for effective natural attenuation even though significant ethene production is observed. The second line of evidence indicates that daughter products that result from TCE degradation, namely *cis*-1,2-DCE, vinyl chloride, and ethene, are all detected in groundwater at the SWMU in locations that support their provenance from their parent product. In addition, sulfate reduction and chloride production, support the interpretation that anaerobic degradation of chlorinated hydrocarbons is occurring in groundwater. However, the accumulation of vinyl chloride indicates that the natural attenuation process might need to be augmented with enhanced biodegradation.

Within the SWMU 2C, groundwater contaminant plume are two areas which contain significantly elevated chlorinated hydrocarbon concentrations. The area, around MW21 is contaminated with *cis*-1,2-DCE and vinyl chloride; the TCE has apparently been completely biodegraded. The area around MW25 is contaminated with TCE and its daughter products

*cis*-1,2-DCE and vinyl chloride. Vinyl chloride has apparently accumulated across the SWMU and the plume covers approximately 30 acres.

In order to achieve complete degradation of the chlorinated hydrocarbon contaminants at SWMU 2C, active groundwater remediation in combination with attenuation enhancement is recommended. "Hot-spot" remediation could be achieved using technologies which aerate and re-circulate treated groundwater. Some of these technologies include the augmentation of groundwater with compounds which promote enhanced attenuation. There are three possible enhanced attenuation treatments that could also be applied to either the elevated areas of the plume, in combination with active remediation, or the SWMU-wide vinyl chloride plume:

1. The addition of hydrogen would continue the reductive dehalogenation process of TCE, *cis*-1,2-DCE, and vinyl chloride and could be applied to the elevated areas or to the whole site.
2. The addition of oxygen would create aerobic conditions and enhance oxidation. An oxygen-releasing compound could be applied to the elevated areas of vinyl chloride or to the whole vinyl chloride plume.
3. The addition of a carbon source or ammonium with oxygen would enhance cometabolism. The application of a carbon source could be applied to the source areas to reduce TCE, *cis*-1,2-DCE, and vinyl chloride.

The practicality of these options will be addressed in the focused feasibility study for SWMU 2C.

## 9.0 References

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Appendix A-1  
**Summary of Detected Chemicals in Monitoring Well  
Groundwater Samples**

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Summary of Detected Chemicals Monitoring Well Groundwater Samples  
Oceana NAS

Sample Date	OW2C-MW01D-R02 1/29/00	OW2C-MW04-R02 1/28/00	OW2C-MW05-R02 1/31/00	OW2C-MW06-R02 1/30/00	OW2C-MW07-R02 1/29/00	OW2C-MW09D-R02 1/28/00	OW2C-MW09-R02 1/28/00	OW2C-MW10-R02 1/30/00	OW2C-MW11-R02 1/28/00
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1-DICHLOROETHANE	2 U	2 U	5.2	2 U	2 U	2 U	2.2	4.7	6 U
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	1.1 U	0.9 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	1.6	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	2 U	1.4 U	2.1	2 U	2.2	2 U	5.6 E	2.8	2 U
M- AND P-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	2.7	2 U	0.9 U	2 U	2 U
TRICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	10.8	2 U	2 U
VINYL CHLORIDE	2 U	1.8 U	2.1	2 U	3.9	2 U	5.6 E	1.2 U	2.2
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	250	85	190	150	230	300	10 U	150	200 U
CHLORIDE	23	17	8.2	12	23	30	21	21	24
COND (MS/CM)	615	437	943	354	560	545	1,998	446	483
DO	0.23	0.29	0.36	0.2	0.42	0.22	0.47	0.31	0.34
ETHANE (NG/L)	5 U	3.183	5 U	20	40	1.267	1.267	3.7	7.5
ETHENE (NG/L)	5 U	52.0	2.20		12.294	9.738	9.738	1.23	2.24
IRON II	0.5 U	13	15	10	7.2	0.5 U	NA	3.7	7.4 U
IRON III	0.9	1	1.9	0.7	0.6	1.2	7	0.57	0.7 U
MANGANESE	0.5 U	0.5 U	0.57	0.5 U	0.6	0.5 U	NA	0.71	0.6 U
METHANE (UG/L)	11,400	990	11,800	10,600	3,790	320	520	180	240
NITRATE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
PH (unitless)	6.66	5.58	6.34	5.94	5.47	6.84	3.3	5.93	5.65
REDOX (mV)	-206.4	-102.2	-187	-92.9	-147.8	-208.9	99.4	65.9	105.1
SULFATE	0.5 U	89	2	1	1.6	0.5 U	2,070	24	30
SULFIDE	0.11	0.1	0.31	0.08	0.18	0.1	0.08	0.09	0.12 U
TEMP (Celsius)	17.86	16.01	15.93	15.46	19.32	16.22	17.07	17.32	17.54
TOTAL ORGANIC CARBON (TOC)	4.8	12	26	11	14	4.3	22	11	7.5
TURB (NTU)	6.7	16	2,018	1,907	420	18.2	2,016	435.4	890.1

Table A-1  
Summary of Detected Chemicals in Monitoring Well Groundwater Samples  
Oceana NAS

Sample Date	OW2C-MW12-R02 1/30/00	OW2C-MW13-R02 1/29/00	OW2C-MW15-R02 1/30/00	OW2C-MW16-R02 1/30/00	OW2C-MW17-R02 1/30/00	OW2C-MW17-R02-P 1/30/00	OW2C-MW18-R02 1/29/00	OW2C-MW19-R02 1/29/00	OW2C-MW20-R02 1/30/00
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1-DICHLOROETHANE	1.5 U	1.3 U	2 U	2 U	2 U	2 U	3.1	2 U	2 U
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	1.1 U	1.3 U	2 U	2 U	2 U	2 U	2.5	2.2	2 U
M- AND P-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TRICHLOROETHENE	0.8 U	1.0 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
VINYL CHLORIDE	3.9	114.5	2	2 U	2 U	2 U	6.5	4.8	2 U
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	69	225	105	73	90	90	255	250	45
CHLORIDE	39	131	59	41	18	18	39	23	24.5
COND (MS/CM)	462	750	614	551	461	NA	665	758	585
DO	0.13	0.23	0.19	0.5	0.27	NA	1.93	2.51	0.48
ETHANE (NG/L)	951	6,335	3,535	23	1,415	57	100	100	32
ETHENE (NG/L)	1,051	22,969	969	35	568	43	6,814	2,236	42
IRON II	3.9	6.3	0.3	0.5 U	1.2	0.7	5.7	7.7	0.5 U
IRON III	0.5 U	0.6	0.5 U	0.5 U	0.795	0.7	0.5 U	1.3	0.5 U
MANGANESE	0.5 U	0.7	0.5 U	0.5 U	0.5 U	0.5 U	1.1	1.3	0.5 U
METHANE (UG/L)	510	890	970	1.65	15	120	2,900	2,200	10.2
NITRATE	0.5 U	0.5 U	0.5 U	0.5 U					
PH (unitless)	6.06	6	5.88	5.58	6.24	NA	6.19	6.26	5.05
REDOX (mV)	79.3	31.8	34.8	33.9	17.3	NA	23.7	25	87
SULFATE	24	18	38	43	13	13	53	52	68.5
SULFIDE	0.1	0.09	0.12	0.1	0.11	0.1	0.11	0.1	0.11
TEMP (Celsius)	16.49	16.59	16.74	15.03	15.97	NA	16.61	15.25	24.12
TOTAL ORGANIC CARBON (TOC)	7.3	9.3	6.3	3	3	2.7	14	12	7.5
TURB (NTU)	69	77.5	22.8	1,625	835	NA	1.5	321.3	1,576

Summary of Detected Chemicals Monitoring Well Groundwater Samples  
Oceana NAS

Sample Date	OW2C-MW21-R02 1/28/00	OW2C-MW22-R02 1/30/00	OW2C-MW23-R02 1/30/00	OW2C-MW24-R02 1/28/00	OW2C-MW25-R02 1/29/00	OW2C-MW25-R02-P 1/29/00
<b>Chemical Name</b>						
<b>Volatile Organic Compounds (UG/L)</b>						
1,1-DICHLOROETHANE	12.3	6.4	2 U	19	2 U	2 U
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROETHENE	2 U	2 U	2 U	47 E	2 U	2 U
1,4-DICHLOROETHENE	2 U	2 U	2 U	4.9	3.1	2.8 U
BENZENE	2 U	0.73	7.4	4.2	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	124 E	2 U	2 U
CIS-1,2-DICHLOROETHENE	35 E	2 U	2 U	2 U	19	21
M- AND P-XYLENE	2 U	2 U	2 U	3.5 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	6.8	2 U	2 U
TOLUENE	3 U	3 U	3 U	2.1	3 U	3 U
TRANS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	9.9	12
TRICHLOROETHENE	6.5	2 U	2 U	2 U	2 U	2 U
VINYL CHLORIDE	124 E	5.9	5.2	55 E	37.3	31.6 E
<b>Wet Chemistry (MG/L)</b>						
ALKALINITY	150 U	200	240	270 U	280	270
CHLORIDE	39	14	24	50	34.4	34.4
COND (MS/CM)	397	447	570	651	751	NA
DO	0.33	0.36	0.29	0.4	0.43	NA
ETHANE (NG/L)	9.570	4.782	1.67	370.458	626	681
ETHENE (NG/L)	51.604	1.260	6.015	20.461	27.064	28.185
IRON II	6	12	11 U	49	17	16.7 U
IRON III	0.6	1.2	0.5 U	2.8	1.7	2 U
MANGANESE	0.5 U	1.1	0.5 U	0.5 U	1.5	1.5 U
METHANE (UG/L)	1,410	2,220	6,640	6,550	4,920	6,340
NITRATE	0.5 U					
PH (unitless)	5.48	6.05	6.15	5.64	5.38	NA
REDOX (mV)	79.4	121.2	140.2	170	136.5	NA
SULFATE	17	0.8	19	3.7	6.2	6.2
SULFIDE	0.1 U	0.16	0.11	0.13 U	0.09	0.1
TEMP (Celsius)	15.5	16.36	18.1	18.6	17.72	NA
TOTAL ORGANIC CARBON (TOC)	8.6	1.6	14	19	21	29
TURB (NTU)	57.2	30.3	538.8	111	264.4	NA

Appendix A-2

**Summary of Detected Chemicals in DPT Groundwater Samples**



Table A-2  
Raw Groundwater Results  
SWMU 2C DW Locations  
Oceana NAS

Sample Date	OW2C-DW04-03 02/24/2000	OW2C-DW04-09 02/24/2000	OW2C-DW04-15 02/24/2000	OW2C-DW05-03 02/24/2000	OW2C-DW05-09 02/24/2000	OW2C-DW05-15 02/24/2000	OW2C DW06-09 02/24/2000	OW2C-DW06-15 02/24/2000	OW2C-DW07-09 02/26/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	2 U	4.8	1.5	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	1.7	2 U	2 U	2 U	2 U	2 U	2 U
BROMOFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	2 U	2 U	2 U	0.8	39	14	8.5	21	8.7
METHYLENE CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	1.6	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3 U	4.8	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	2 U	5.8	2 U	2 U	1.8	2 U	1.7	2.1	1.2
TRICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
VINYL CHLORIDE	2 U	2.9	6.7	13	353	25	82	67	62
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	NA	352	225	120	350	180	400	250	320
CHLORIDE	NA	19	42	12	39	45	120	35	12
COND (MS/CM)	NA	939	790	NA	925	779	561	497	554
DO	NA	0.12	3	NA	0.14	2.4	0	0	10.0
ETHANE (NG/L)	NA	684	126	53	544	158	484	223	1,941
ETHENE (NG/L)	NA	33,835	7,267	2,355	31,033	2,984	16,044	11,091	17,321
IRON II	22	40	8.8	12	19	8.8	38	9.6	37
IRON III	15	1.9	0.5	1.2	6.8	0.5	3.6	0.7	1.5
MANGANESE	0.5 U	0.5 U	0.5	0.6 U	2	0.5 U	1.5	0.7	0.5 U
METHANE (UG/L)	NA	10,860	2,410	3,950	3,820	399	11,030	4,590	6,590
PH (unitless)	NA	5.95	5.63	NA	5.91	5.85	6.1	5.98	6.16
REDOX (mV)	NA	70.2	23.9	NA	14.7	1	114.6	45.4	220.1
SULFATE	10	0.5 U	1.5	3.1	0.5 U	21	0.5 U	0.5 U	2.7
SULFIDE	NA	0.12	0.11	0.14	0.12	0.15	0.14	0.15	0.13
TEMP (Celsius)	NA	15.32	18.12	NA	18.04	18.13	16.11	20.03	15.74
TOTAL ORGANIC CARBON (TOC)	NA	29	14	22	28	20	74	21	15
TURB (NTU)	NA	61.5	24	NA	17.1	13.6	77.6	71.1	1.7

Te  
Raw Growth Results  
SWMU 2C Locations  
Oceana NAS

Sample Date	OW2C-DW08-09 02/26/2000	OW2C-DW09-09 02/26/2000	OW2C-DW10-09 02/26/2000	OW2C-DW11-09 02/26/2000	OW2C-DW12-09 02/26/2000	OW2C-DW13-09 02/26/2000	OW2C-DW14-09 02/26/2000	OW2C-DW15-09 02/27/2000	OW2C-DW16-09 02/26/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	4.2	18 U	5.4	4.4	12	76 U	60 U	13	2.1
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	2 U	1.3	2 U	2.2	2.1	1.5 U	1.2 U
BROMOFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	1.4 U	6.1	3.6	3.1	142	60 U	32.9	52	26
METHYLENE CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	1.8 U	2 U	2 U	2 U	2 U	3.9 U	2 U	2 U	2 U
TOLUENE	4.8	3.1	3 U	3 U	3 U	17	3.6	3 U	3 U
TRANS-1,2-DICHLOROETHENE	4.3	3.1	1.1	9.2	12	11	3.4	7.9	5
TRICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
VINYL CHLORIDE	220	123	350	292 E	250	373 E	203	264	182
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	333	350	350	400	340	410	400	360	360
CHLORIDE	16	17	23	20.3	25	29	25	27	25
COND (MS/CM)	436	700	617	663	625	690	660	635	638
DO	0.08	0.01	8.52	0	0.01	12.05	0	1.99	10
ETHANE (NG/L)	1.599	4.935	1373	2.166	1.609	385	1.284	704	691
ETHENE (NG/L)	26.668	16.367	53.760	44.142	19.752	37.471	26.621	36.450	28.264
IRON II	48	37	53	34	24	17	22	18 E	20
IRON III	1.7	1.7	1.3	1.1	1.2	0.8	1.1	0.7	1.1
MANGANESE	0.5 U	0.5 U	0.5 U	0.8	1.3	1.5	1.6	1.4	1.2
METHANE (UG/L)	10,380	10,780	7,150	8,210	6,380	7,420	8,300	8,400	8,540
PH (unitless)	5.92	5.96	5.96	5.81	5.8	5.83	5.81	5.81	5.81
REDOX (mV)	53.5	66.3	180.1	42.3	20.9	269.6	28.6	142.6	27.6
SULFATE	0.5 U	0.5 U	0.5 U	10	0.5 U	0.84	1.3	0.5 U	0.5 U
SULFIDE	0.16	1.3	0.12	0.14	0.13	0.14	0.18	0.1	0.17
TEMP (Celsius)	14.93	15.64	15.25	15.96	16	15.5	15.69	17.25	15.65
TOTAL ORGANIC CARBON (TOC)	23	21	31	35	130	36	66	48	75
TURB (NTU)	98.1	49.9	6.1	32.9	52.3	20	77.9	1.841	58.7

Table A-2  
 Raw Groundwater Results  
 SWMU 2C DW Locations  
 Oceana NAS

Sample Date	OW2C-DW17-09 02/27/2000	OW2C-DW17-09-P 02/27/2000	OW2C-DW18-09 02/27/2000	OW2C-DW19-09 02/26/2000	OW2C-DW19-09-P 02/26/2000	OW2C-DW20-09 02/26/2000	OW2C-DW21-09 02/27/2000	OW2C-DW22-09 02/27/2000	OW2C-DW23-09 02/27/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BROMOFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
METHYLENE CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TRICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
VINYL CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	325	326	380	350	350	350	275	285	350
CHLORIDE	24	24	27	24	24	24	26	24	25
COND (MS/CM)	350	NA	1117	573	NA	651	974	710	803
DO	07	NA	1.42	1.05	NA	0	0	12.7	0
ETHANE (NG/L)	364	359	835	511	603	575	708	667	567
ETHENE (NG/L)	21,096	21,555	4,519	23,928	20,807	9,742	18,577	20,248	13,723
IRON II	17	14	33 E	19	8.7	6	31 E	27 E	23.7 E
IRON III	0.7	0.7	1.6	0.8	0.9	1	0.9	0.9	1.3
MANGANESE	2.7	2.7	3.959	3.3	3.2	2.6	2.3	2.3	3.7
METHANE (UG/L)	689	7,190	4,910	5,160	5,780	8,340	7,490	8,140	7,000
PH (unitless)	5.82	NA	5.88	5.93	NA	5.86	6.08	5.85	6.08
REDOX (mV)	56.1	NA	97	291.1	NA	42.1	44.5	258.9	54
SULFATE	2.2	2.4	0.5 U	0.5 U	0.5 U	2.0	0.5 U	0.5 U	0.5 U
SULFIDE	0.14	0.14	0.1	0.12	0.13	0.11	0.1	0.1	0.09
TEMP (Celsius)	16.74	NA	18.89	16.01	NA	18.41	17.17	17.65	16.49
TOTAL ORGANIC CARBON (TOC)	23	23	29	26	38	24	27	25	42
TURB (NTU)	340	NA	1837	3	NA	5.1	98.7	10	3,039

T  
 Raw Gro Results  
 SWMU 2 Locations  
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Sample Date	OW2C-DW24-09 02/27/2000	OW2C-DW25-09 02/27/2000	OW2C-DW26-09 02/27/2000	OW2C-DW27-09 02/27/2000	OW2C-DW28-09 02/27/2000	OW2C-DW29-09 02/27/2000	OW2C-DW30-15 02/27/2000	OW2C-DW31-15 02/28/2000	OW2C-DW32-15 02/28/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	1.9	5.1	8.7	2.1	2.1	2.1	3.1	3.1	13.1
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	0.7	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	0.9	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	13.0	2 U	0.7	0.7	2 U	2 U	2 U	2 U	2 U
BROMOFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROBENZENE	1.8	2 U	1.1	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	31	26	23	99	18	2 U	276	67	61.0
METHYLENE CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	9.7	2.9	4.5	4.9	19.1	2 U	4.9	4.1	2.1
TRICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	12	5.2	8.2
VINYL CHLORIDE	196	191	144	129	95	2	697	6175	485
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	360	375	400	350	490	218	210	210	170
CHLORIDE	24	26	23	22	18	7.3	28	27	28.1
COND (MS/CM)	865	781	828	793	1,013	597	786	633	720
DO	0	0	2.68	0.02	1.84	0.02	10.3	0.25	0.23
ETHANE (NG/L)	524	1,161	373	500	434	1,233	5,948	3,430	15,142
ETHENE (NG/L)	24,953	20,814	22,737	15,266	11,008	3,075	83,902	143,726	81,051
IRON II	24 E	17	30	21	15	17	19.2	14 E	19 E
IRON III	1.2	1.5	1.3	1.3	1.3	1.2	0.8	0.8	0.6
MANGANESE	2.9	2	2.3	1.6	0.9	0.7	1.1	0.6	1.1
METHANE (UG/L)	0.050	7.540	7.160	7.340	5.740	10.280	1.860	3.320	2.750
PH (unitless)	6.09	6.03	5.89	6	6.04	6.28	5.68	6.8	6.75
REDOX (mV)	-48.5	54.1	-92.2	-94.4	-101.7	-97.1	180.3	25.1	-46.0
SULFATE	0.5 U	0.5 U	0.5 U	0.5 U	47	0.5 U	136	26	73
SULFIDE	0.11	0.17	0.17	0.22	0.16	0.31	0.1	0.1	0.11
TEMP (Celsius)	17.63	18.36	18.29	18.10	18.16	20.61	16.6	17.09	18.07
TOTAL ORGANIC CARBON (TOC)	59	23	25	21	20	19	11	17	13
TURB (NTU)	279.5	1,654	1,850	167	29.9	166.4	16	0.1	5

Table A-2  
Raw Groundwater Results  
SWMU 2C DW Locations  
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Sample Date	OW2C-DW33-15 02/28/2000	OW2C-DW34-15 02/29/2000	OW2C-DW35-15 02/29/2000	OW2C-DW36-15 02/29/2000	OW2C-DW37-15 02/29/2000	OW2C-DW38-15 02/28/2000	OW2C-DW39-15 02/29/2000	OW2C-DW40-15 02/29/2000	OW2C-DW41-15 02/28/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	4.2	2 U	3.8	5.8	3.5	5.2	2.8	4.4	4.4
1,1-DICHLOROETHENE	0.8 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2.4	2.2	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BROMOFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	2.0	3.6	3.7	7.0	6.4	7.7	3.2	1.0	5.3
METHYLENE CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	5.3	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TRICHLOROETHENE	12	10	6.5	5.1	4.1	6.7	5.4	5.8	6.1
VINYL CHLORIDE	778	249	76	25	18	327	129	27	25
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	170	156	230	210	225	255	230	180	250
CHLORIDE	NA	28	86	98	93	88	129	94	88
COND (MS/CM)	676	697	782	660	551	461	660	705	614
DO	1.03	0.41	0.37	0.18	0.19	0	0.4	0.38	0.18
ETHANE (NG/L)	3.579	7.512	21.787	57.029	42.492	50.899	5.264	25.702	75.760
ETHENE (NG/L)	104.009	65.211	18.744	16.049	4.028	14.563	71.699	28.368	15.156
IRON II	NA	2 E	12 E	8.3	5.2	11	11	12 E	8.9
IRON III	NA	0.5	0.7	0.5 U					
MANGANESE	NA	0.7	0.8	0.7	0.5	0.7	0.6	0.6	0.7
METHANE (UG/L)	2.530	2.260	1.976	2.502	2.235	2.620	2.771	2.195	2.950
PH (unitless)	3.69	5.94	8.92	5.75	5.83	3.94	5.89	5.89	5.74
REDOX (mV)	325.3	-27	-29.9	-30.2	-325.2	-28.3	-17.3	-26.2	-4.2
SULFATE	NA	2.1	9	5.1	8.6	3.9	4.2	4.1	4.2
SULFIDE	NA	0.09	0.11	0.11	0.11	0.11	0.14	0.13	0.09
TEMP (Celsius)	15.21	14.8	15.38	15.66	15.94	15.48	16.12	17.03	16.12
TOTAL ORGANIC CARBON (TOC)	15	13	12	14	12	15	14	14	13
TURB (NTU)	783.5	20.1	130.4	23.8	20.1	3.4	50	6.2	3.5

T-2  
 Raw Gro Results  
 SWMU 2 Locations  
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Sample Date	OW2C-DW42-15 02/28/2000	OW2C-DW43-15 02/29/2000	OW2C-DW43-15-P 02/29/2000	OW2C-DW44-15 03/01/2000	OW2C-DW45-15 03/01/2000	OW2C-DW46-15 03/01/2000	OW2C-DW47-15 03/01/2000	OW2C-DW48-15 03/01/2000	OW2C-DW49-09 02/27/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	6.3	0.9	0.9	4.4	4.5	6.6	5.6	2 U	5.9
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	1.3	3	1.4	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	2 U	2 U	2 U	4.4	2 U	0.7 U	1.8 U
BROMOFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	3.7	4.6	1.6 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	1.1	337.2	96.2	4.6	0.9	2.6	5.1	475	9.7
METHYLENE CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	2 U	3.3	0.5	2 U	2 U	2 U	2 U	5.6	2 U
TRICHLOROETHENE	5.4	19	11	4.6	3.6	19.7	3.6	8.6	2 U
VINYL CHLORIDE	30	552	568	11	20	26	23	376	176
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	180	270	270	190	200	150	250	200	145
CHLORIDE	40	28	28	41	38	21	32	24	27
COND (MS/CM)	444	587	NA	906	817	644	629	425	649
DO	11.05	0.19	NA	0.27	0.8	0.9	0.22	0.22	0.57
ETHANE (NG/L)	8030	4853	4857	50423	62892	34811	36267	5699	1083
ETHENE (NG/L)	17130	51673	70336	7757	10327	6627	38763	62365	38307
IRON II	11	3 E	4 E	9.9	8.6	9.5	13 E	12 E	21 E
IRON III	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.6
MANGANESE	0.6	0.6	0.6	0.7	0.7	0.6	0.7	0.5	1.9
METHANE (UG/L)	3170	2328	2617	2641	2571	1540	2037	2615	3950
PH (unitless)	5.73	5.73	NA	6	5.93	5.93	5.91	5.91	5.96
REDOX (mV)	-195.1	-339	NA	-14	-1.6	-9.7	19.4	11.3	-20.3
SULFATE	65	3.9	NA	2.8	6.3	6.7	2.8	4.1	0.5 U
SULFIDE	0.1	0.09	0	0.18	0.18	0.2	0.09	0.11	0.11
TEMP (Celsius)	17.48	17.66	NA	16.45	16.25	14.76	16	16.83	16.26
TOTAL ORGANIC CARBON (TOC)	18	17	13	12	13	12	19	13	68
TURB (NTU)	7.5	4.6	NA	10.6	7.9	4.2	47.8	66.3	900

Table A-2  
Raw Groundwater Results  
SWMU 2C DW Locations  
Oceana NAS

Sample Date	OW2C-DW50-09 02/28/2000	OW2C-DW50-09-P 02/28/2000	OW2C-DW51-09 02/28/2000	OW2C-DW52-15 03/01/2000	OW2C-DW53-15 03/01/2000	OW2C-DW54-09 02/29/2000	OW2C-DW55-09 02/29/2000	OW2C-DW56-09 02/29/2000	OW2C-DW57-09 02/29/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	38.5	38.5	1.1	8.1	2	2 U	2 U	5.8	2 U
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	2 U	2 U	2 U	8.4	2 U	2 U	2 U
BROMOFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	2.4	2.08	35.9	19	2.1	2 U	2 U	1.5.1	2 U
METHYLENE CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3.3	3.3	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	1.4	1.3	1.8	2 U	2 U	2 U	2 U	2 U	2 U
TRICHLOROETHENE	2 U	2 U	2 U	5.2	5.7	2 U	2 U	1.9.1	2 U
VINYL CHLORIDE	43.4	42.0	56.0	41.4.2	5.88	3.9	2 U	4.6	2 U
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	250	270	250	220	210	150	260	510	250
CHLORIDE	28	30	31	30	31	28	22	17	6.8
COND (MS/CM)	692	NA	66	762	739	NA	847	792	753
DO	0.43	NA	0.42	0.22	0.23	NA	0.6	0.2	0.34
ETHANE (NG/L)	2,057	392	1,004	54,236	18,467	4,667	250	5 U	180
ETHENE (NG/L)	20,240	23,224	57,073	22,291	53,032	540	166	8,132	5 U
IRON II	15 E	13 E	23 E	1.1	1.1	32 E	23 E	65 E	42 E
IRON III	0.7	0.5 U	1.2	0.6	0.5	1.2	1.3	2.9	1.7
MANGANESE	1.2	2	2	0.6	0.5 U	1.9	1.8	0.5 U	0.5 U
METHANE (UG/L)	4,939	6,262	3,073	2,662	1,930	5,484	1,507	7,668	3,886
PH (unitless)	5.93	NA	5.0	5.93	5.92	NA	5.92	6.77	6.15
REDOX (mV)	15.3	NA	21.3	7.3	13.4	NA	30.4	29.3	76.1
SULFATE	0.5 U	0.5 U	0.5 U	5.9	12	0.5 U	4	0.5 U	0.5 U
SULFIDE	0.12	0.13	0.1	0.16	0.13	0.09	0.1	0.12	0.1
TEMP (Celsius)	15.89	NA	15.93	16.27	16.02	NA	17.13	16.95	16.1
TOTAL ORGANIC CARBON (TOC)	28	30	28	13	13	36	3	42	18
TURB (NTU)	39.9	NA	7	7	40.5	NA	12.3	26.2	62.5

Raw Gro Results  
 SWMU 2 Locations  
 Oceana NAS

Sample Date	OW2C-DW58-15 03/07/2000	OW2C-DW59-15 03/07/2000	OW2C-DW60-15 03/07/2000	OW2C-DW61-15 03/07/2000	OW2C-DW62-09 03/07/2000	OW2C-DW63-15 03/07/2000	OW2C-DW64-15 03/07/2000	OW2C-DW65-09 03/07/2000	OW2C-DW65-09-P 03/07/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BROMOFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
METHYLENE CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TRICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
VINYL CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	NA	NA	NA	NA	160	NA	NA	NA	NA
CHLORIDE	43	20	49	22	10	14	87	18	29
COND (MS/CM)	381	336	336	18	404	169	162	669	NA
DO	0.19	0.13	0.27	0.11	0.34	0.19	0.19	0.6	NA
ETHANE (NG/L)	NA								
ETHENE (NG/L)	NA								
IRON II	NA	NA	NA	NA	17	NA	NA	NA	NA
IRON III	NA	NA	NA	NA	1	NA	NA	NA	NA
MANGANESE	NA	NA	NA	NA	0.5	NA	NA	NA	NA
METHANE (UG/L)	NA								
PH (unitless)	6.25	6.1	6.65	5.92	6.45	6.81	6.77	6.27	NA
REDOX (mV)	17.5	3.8	367.3	9.2	34.2	29.6	298.6	19.4	NA
SULFATE	NA	NA	NA	NA	0.5 U	NA	NA	NA	NA
SULFIDE	NA								
TEMP (Celsius)	16.64	15.36	17.64	16.57	16.63	18.15	14.55	16.83	NA
TOTAL ORGANIC CARBON (TOC)	NA								
TURB (NTU)	35.3	21.3	3.4	35.5	20.9	162.6	5.2	4	NA

Table A-2  
Raw Groundwater Results  
SWMU 2C DW Locations  
Oceana NAS

Sample Date	OW2C-DW66-09 03/07/2000	OW2C-DW67-15 03/07/2000	OW2C-DW68-15 03/07/2000	OW2C-DW69-15 03/07/2000	OW2C-DW70-15 03/07/2000	OW2C-DW71-15 03/07/2000	OW2C DW72-15 03/07/2000	OW2C-DW73-15 03/08/2000	OW2C-DW74-15 03/07/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BROMOFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
METHYLENE CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TRICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
VINYL CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	NA								
CHLORIDE	2	3	10	35	23	17	23	24	26
COND (MS/CM)	605	287	259	286	376	141	188	294	342
DO	0.19	0.13	0.13	0.16	0.16	0.44	0.76	0.17	0.23
ETHANE (NG/L)	NA	NA	NA	NA	18.85	NA	NA	NA	NA
ETHENE (NG/L)	NA								
IRON II	NA								
IRON III	NA								
MANGANESE	NA								
METHANE (UG/L)	NA								
PH (unitless)	6.17	5.58	6.08	5.92	5.97	5.72	5.64	5.8	6.2
REDOX (mV)	-268	3.2	2.2	9.3	-236.3	35.8	36.7	36.5	125
SULFATE	NA								
SULFIDE	NA								
TEMP (Celsius)	16.63	16.51	16.04	16.92	16.89	14.19	16.47	16.73	18.33
TOTAL ORGANIC CARBON (TOC)	NA								
TURB (NTU)	0.9	1.05	3.15	82.3	74.8	101.8	203.7	161.5	18.3

T<sub>F</sub>  
 Raw Gror Results  
 SWMU 2L Locations  
 Oceana NAS

Sample Date	OW2C-DW74-15-P 03/07/2000	OW2C-DW75-15 03/08/2000	OW2C-DW76-09 03/07/2000	OW2C-DW76-15 03/07/2000	OW2C-DW77-09 03/08/2000	OW2C-DW78-15 03/08/2000	OW2C-DW79-15 03/08/2000	OW2C-DW80-15 03/08/2000	OW2C-DW80-15-P 03/08/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	40 U	17	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	15 U	28	40 U	13	2 U	24	2 U	2 U	2 U
1,1-DICHLOROETHENE	21	2 U	40 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	40 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	40 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	40 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	40 U	2 U	2 U	2 U	2 U	21	21
BROMOFORM	2 U	2 U	40 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROBENZENE	2 U	2 U	40 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	16 U	40 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	40 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	4 U	19	56	71 E	2 U	129	93 U	2 U	2 U
METHYLENE CHLORIDE	8 U	2 U	40 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	40 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3 U	3 U	60 U	2 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	2 U	2 U	40 U	74	2 U	22	2 U	2 U	2 U
TRICHLOROETHENE	26	62	40 U	2 U	2 U	24	17 U	2 U	2 U
VINYL CHLORIDE	12	40	210	134 E	78	101	38	16 U	14 U
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	NA	NA	NA	NA	NA	NA	NA	NA	NA
CHLORIDE	NA	39	NA	34	16	20	12	24	24
COND (MS/CM)	NA	591	548	NA	612	415	236	523	NA
DO	NA	0.22	1.54	NA	0.19	0.12	0.99	0.26	NA
ETHANE (NG/L)	NA	NA	NA	NA	NA	NA	NA	NA	NA
ETHENE (NG/L)	NA	NA	NA	NA	NA	NA	NA	NA	NA
IRON II	NA	NA	NA	NA	NA	NA	NA	NA	NA
IRON III	NA	NA	NA	NA	NA	NA	NA	NA	NA
MANGANESE	NA	NA	NA	NA	NA	NA	NA	NA	NA
METHANE (UG/L)	NA	NA	NA	NA	NA	NA	NA	NA	NA
PH (unitless)	NA	6.04	5.95	NA	6.26	5.99	6.14	5.97	NA
REDOX (mV)	NA	10.1	4.1	NA	75.9	48.8	26.8	-166.9	NA
SULFATE	NA	NA	NA	NA	NA	NA	NA	NA	NA
SULFIDE	NA	NA	NA	NA	NA	NA	NA	NA	NA
TEMP (Celsius)	NA	18.98	16.54	NA	16.56	17.23	15.08	16.62	NA
TOTAL ORGANIC CARBON (TOC)	NA	NA	NA	NA	NA	NA	NA	NA	NA
TURB (NTU)	NA	263.1	53	NA	55.7	296.8	552	0.2	NA

Table A-2  
Raw Groundwater Results  
SWMU 2C DW Locations  
Oceana NAS

Sample Date	OW2C-DW81-15 03/08/2000	OW2C-DW82-15 03/08/2000	OW2C-DW83-15 03/08/2000	OW2C-DW84-15 03/08/2000	OW2C-DW85-15 03/08/2000	OW2C-DW86-15 03/08/2000	OW2C-DW87-15 03/08/2000	OW2C-DW88-15 03/08/2000	OW2C-DW89-15 03/09/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	2 U	2 U	2 U	1.8	2.3	2.0	2 U	0.7 U	6 U
1,1-DICHLOROETHENE	3 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	2 U	2 U	2 U	4.6	3	2 U	2.6
BROMOFORM	2 U	2 U	2 U	2 U	2 U	1.2	2 U	2 U	2 U
CHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	3.7
METHYLENE CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	1.2	2 U	2 U
TOLUENE	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TRICHLOROETHENE	2 U	2 U	2 U	2 U	2.1	2 U	2 U	3	2.9
VINYL CHLORIDE	2 U	2 U	2 U	2 U	2 U	3.6	2.5	6.6	2.9
<b>Wet Chemistry (MG/L)</b>									
ALKALINITY	NA								
CHLORIDE	77	77	82	77	20	37	25	16	26
COND (MS/CM)	478	378	113	373	452	569	569	404	363
DO	0.23	0.07	0.14	0.17	0.09	0.25	0.21	0.19	0.28
ETHANE (NG/L)	NA								
ETHENE (NG/L)	NA								
IRON II	NA								
IRON III	NA								
MANGANESE	NA								
METHANE (UG/L)	NA								
PH (unitless)	6.12	5.89	5.49	5.73	6.1	5.68	6.24	6.04	6.01
REDOX (mV)	17.5	16.1	56.9	12.1	15.2	224	46.1	20.6	27.2
SULFATE	NA								
SULFIDE	NA								
TEMP (Celsius)	17.38	16.8	21.18	17.47	16.2	14.09	18.91	21.16	20.11
TOTAL ORGANIC CARBON (TOC)	NA								
TURB (NTU)	16.4	26.47	187.2	67.5	366	13.8	3.8	93.0	66.4

2  
Raw Gr Results  
SWMU Locations  
Oceana NAS

Sample Date	OW2C-DW90-15	OW2C-DW91-15	OW2C-DW92-09	OW2C-DW93-15	OW2C-DW93-15-P	OW2C-DW94-15	OW2C-DW95-15	OW2C-DW96-15	OW2C-DW97-15
	03/09/2000	03/09/2000	03/09/2000	03/09/2000	03/09/2000	03/09/2000	03/09/2000	03/09/2000	03/09/2000
<b>Chemical Name</b>									
<b>Volatile Organic Compounds (UG/L)</b>									
1,1,2-TRICHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHANE	2 U	2 U	0.75 U	2 U	2 U	2 U	2 U	2 U	2 U
1,1-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2,4-TRICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,4-DICHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
BENZENE	2 U	2 U	2 U	0.9 U	2 U	2 U	2 U	2 U	2 U
BROMOFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROBENZENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROETHANE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CHLOROFORM	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
CIS-1,2-DICHLOROETHENE	1.9 U	2.2 U	2.9 U	7.2 U	7.5 U	3.2 U	8.0 U	6.0 U	9.1 U
METHYLENE CHLORIDE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
O-XYLENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TOLUENE	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U	3 U
TRANS-1,2-DICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
TRICHLOROETHENE	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
VINYL CHLORIDE	5.0 U	1.8 U	18.1 U	26 U	27 U	2 U	198.8 U	696 U	2.1 U
<b>Wet Chemistry (MGL)</b>									
ALKALINITY	NA	NA	NA	NA	NA	NA	NA	NA	NA
CHLORIDE	46	49	75	36	38	23	21	26	23
COND (MS/CM)	587	NA	414	597	NA	424	388	579	469
DO	0.19	NA	0.16	0.18	NA	0	0.19	0	0.16
ETHANE (NG/L)	NA	NA	NA	NA	NA	NA	NA	NA	787
ETHENE (NG/L)	NA	NA	NA	NA	NA	NA	NA	NA	6,185
IRON II	NA	NA	NA	NA	NA	NA	NA	NA	9.1
IRON III	NA	NA	NA	NA	NA	NA	NA	NA	NA
MANGANESE	NA	NA	NA	NA	NA	NA	NA	NA	NA
METHANE (UG/L)	NA	NA	NA	NA	NA	NA	NA	NA	84.3
PH (unitless)	8.19	NA	8.17	8.21	NA	5.94	5.74	5.98	6
REDOX (mV)	-20.9	NA	-39.2	-24.7	NA	-18.2	-26.8	-21.7	-2.0
SULFATE	NA	NA	NA	NA	NA	NA	NA	NA	NA
SULFIDE	NA	NA	NA	NA	NA	NA	NA	NA	NA
TEMP (Celsius)	18.51	NA	18.47	18.88	NA	17.61	15.37	15.79	16.93
TOTAL ORGANIC CARBON (TOC)	NA	NA	NA	NA	NA	NA	NA	NA	15
TURB (NTU)	33.2	NA	12.8	26.8	NA	46.7	182.4	27.7	665.8